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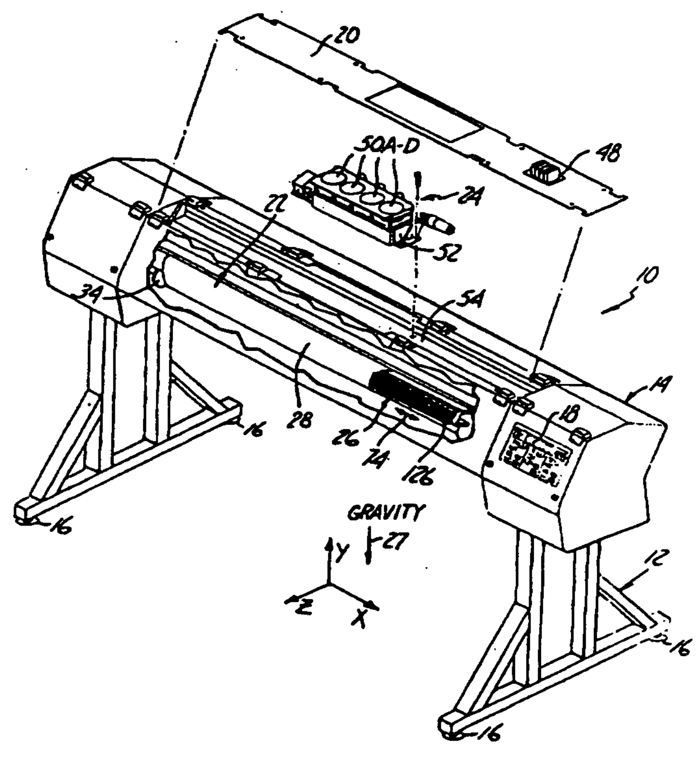
(54) Title: LARGE FORMAT INK JET PRINTER AND INK SUPPLY SYSTEM

(57) Abstract

A scanning head ink jet printer (10) for high-speed, large formatoutput of graphics quality utilizes a high throughput ink delivery system (24), variable paper advance interlacing at a variety ofsaber angles, a printing medium handling system (22), and in certain embodiments, multiple print heads (84, 86) disposed on a common carriage (88). The medium handling system (22) includes paper tensioning subassemblies (512, 519) to maintain constant tension during printing and, when used with hot melt inks, during a post-imaging heating process to cure the image into the printing medium (28). Memory units (48, 530) provide characteristics information regarding ink and printing medium (28) for use by a controller (532, 1402).



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LARGE FORMAT INK JET PRINTER AND INK SUPPLY SYSTEM

BACKGROUND OF THE INVENTION

This present invention relates to ink jet printing systems capable of printing on large scale print mediums at a high print rate with improved color quality and print resolution. The invention also relates to a new and improved ink supply system which has numerous advantages over prior art ink supply systems and which helps to achieve the above-mentioned printing capabilities of the ink jet printing system.

Ink jet printing involves placing tiny ink droplets formed by one or more ink jets onto particular locations on the printing medium. The ink droplets solidify or dry on the printing medium, forming small dots. Any number of these small dots, when perceived some viewing distance away from the paper, are perceived as a continuous-tone visual image. Both text and graphic images may be printed with ink jet printing.

The printed image from an ink jet printer is made up of a grid-like pattern of potential dot locations, called picture elements or "pixels". Small-format documents are ones commonly viewed from 1-6 feet away. Ink jet printers designed to print small-format documents operate at a print resolution of 200 to 300 pixels per inch (40,000 to 90,000 pixels per square inch) and a maximum width of 24 inches. Large-format printers are used to print large posters and billboards, intended for viewing from ten to several hundreds of feet away. Typically, these printers print at a resolution of 6 to 12 pixels per inch over a medium width of up to 16.4 feet.

Presently there are two primary types of jets which can be used in ink jet printers. Thermal ink jets use a thin film resistor to vaporize a small portion of ink and create a minute bubble within the ink. The bubble forces a small droplet of ink through the jet nozzle. Piezoelectric jets use a substrate which is electrically pulsed to create a pressure wave which in turn shoots a droplet of ink through the jet nozzle. A method of making a piezoelectric ink jet is taught in U.S. Patent 5,265,315 to Hoisington et al., which is incorporated

herein by reference.

Ink jet printers may further be classified as "on demand", for which ink droplets are formed only at the particular pixel locations needed, or as "continuous", for which ink droplets are formed at each pixel location, but some droplets are deflected away before they contact the paper. Additionally, the inks used in ink jet printers may vary. Some ink jet printers utilize aqueous ink, which is liquid at room temperature but is generally absorbed into the fibers of the paper. Others use semi-liquid or semi-solid inks. Yet others use hot melt ink, which is solid at room temperature but is applied in a heated liquid condition and then effectively frozen onto the paper surface. Typically, the semi-liquid, semi-solid and hot melt inks employ little or no solvent and are collectively referred to as non-aqueous, phase-change inks. The ink jet configuration of the present invention applies equally to all these various types of ink jet printers, but is particularly contemplated for on demand, piezoelectric, non-aqueous, phase-change ink jet printing, such as hot melt ink jet printing.

Color ink jet printers typically use the four subtractive primary colors, cyan, magenta, yellow and black ("CMYK"). Color blending of these four ink colors is achieved through either of two mechanisms. First, the ink jet printer may lay down multiple colors of ink on the same pixel location, thus combining ink colors at that pixel. The particular color combination caused by having multiple ink colors at a particular pixel location may be affected by the order of printing the various colors, as well as the homogeneity (or non-homogeneity) of ink mixing.

Second, the ink jet printer may lay down a single color of ink at a given pixel location so that when viewed at a distance, the eye will blend colors from adjacent pixel locations. Thus, for instance, a number of exclusively magenta and yellow dots may be laid down in an area of the image, with no pixel location receiving two colors of ink. Rather than perceiving individual magenta and yellow dots, the eye will blend the adjacent dots to perceive an orange color. In practice, ink jet color printers use both ink blending at

particular pixel location and perception blending across pixel locations to create various colors and shades. Often a substantial number of the pixels of the image will go without having a dot of ink placed on them. This allows the perceived visual image to have a proper lightness/darkness or value. Through both forms of color blending, ink jet printers using only four colors of ink can visually reproduce full color images.

Ink jet printers generally move a print head containing the ink jets horizontally across the print image, while advancing the paper lengthwise in between passes or scans of the print head. To increase the rate of printing, numerous jets per color have been used to create a wider print head swath or "stroke". Prior ink jet color printers have utilized a single head having 64 linearly aligned jets. To print with four (CMYK) colors, four sets of 16 adjacent jets are each supplied with one of the ink colors to print 16 rows of pixels of each color. Each jet is vertically offset one pixel from the adjacent jets. With this previous 64-jet printer, the paper advance is 16 pixels after each scan (i.e., one quarter of the width of the 64 pixel print stroke), such that each scan of the printer head orients a jet of another ink color over each pixel row printed in a prior color.

Ideally, ink jet printing would occur by vertically-aligned (i.e., aligned in the direction of paper travel, perpendicular to the direction of print head travel) printer jets each mounted one pixel beneath the preceding jet. However, present printer head technology limits the minimal spacing between jets. For instance, piezoelectric jets of the type discussed in U.S. Patent No. 5,265,315 to Hoisington et al. are presently limited to approximately 0.027 inches spacing between adjacent jets, or approximately 37 jets per linear inch. Ink reservoir/firing chamber space is presently the critical factor in preventing closer spacing. To attain 37 jets per linear inch spacing, chambers are alternately located above and below the jets. Resolution of 37 dots per inch is quite unsatisfactory in reproducing closely-viewed visual images at resolutions adequate to produce a pleasing visual effect, such as graphics quality, large-

format ink jet printers.

To achieve a higher print resolution, prior linear jet arrays have been oriented at an angle in relation to the direction of print head travel, known as the "saber" angle. By angling the linear jet array, the vertical spacing between jets becomes smaller, and the resolution of the resulting image is increased. To provide a resolution of 300 dots per inch, the line of jets has been angled such that each jet is approximately 1/300th of an inch vertically beneath the preceding jet. The horizontal spacing between jets should be a multiple of the vertical spacing between pixel rows, to aid in developing a grid pattern of pixel locations having matching horizontal and vertical resolutions. Because the vertical spacing between pixel rows is 1/300th of an inch, the horizontal spacing between jets should be a multiple of 1/300th of an inch. With a spacing constraint of 0.027 inches between the jets, 1/300th of an inch vertical spacing leads to a horizontal spacing between jets of 8/300ths of an inch. The saber angle of the line of jets is at a ratio of 8 to 1, resulting in an angle of 7.125°. This is the saber angle presently being used in prior art hot melt ink jet printers.

Prior art scanning print head configurations, with numerous jets per color each mounted one pixel beneath the previous jet, predicate what is known as a "banding" problem. One type of banding occurs if the paper advance is not extremely accurate, such that the paper is advanced slightly more or slightly less than the width of the print swath or stroke (i.e., the vertical extent of the line of jets). Thus, if the paper advances slightly too far a perceptible blank area will occur in the color pattern at the end of each paper advance, between the printed swaths. Conversely, if the paper advance is too short, a perceptible overlap will occur in the color pattern at the beginning of each paper advance, resulting in a darkened region where adjoining swaths overlap.

Other causes can further complicate the banding problem. With some printers, the direction that the print head is traveling for any given scan may affect the order that the different ink colors are laid down on the paper. A different ordering of colors may create a slightly different hue when visually

perceived. For instance, if one band is laid down from left to right with magenta over cyan on a significant number of pixels, and the succeeding band is laid down from right to left with cyan over magenta on a significant number of pixels, a slight color difference between the two bands may be visually detectable.

Banding may also be caused in part by the thermal characteristics of the printing scan. In a hot melt ink system, the top of the band may be laid down first, on a relatively cool piece of paper, whereas the middle and bottom of the band may be laid down on a paper heated by previous ink dots. This difference in heating can affect the ink flow characteristics and cause a visually perceptible difference between the top and bottom of the band.

Banding is also caused by misalignment of ink jet heads in ink jet printers having multiple ink jet heads. These alignment problems become aggravated as the number of jets increase, as the spacing between the furthest jets increases during replacement of any other components of the print heads, and as the ink delivery and mechanical placement of print heads becomes more complicated. Alignment of multiple heads is not easily accomplished through mechanical manipulation of the jets, although compensation for some head alignment problems can be accomplished by adjusting the timing of jet firing between different jets. Calibration techniques can be used to determine what adjustment is necessary.

Various methods have been attempted to compensate for banding problems. For instance, in U.S. Patent 5,075,689 to Hoisington et al., banding was addressed by altering the arrangement of print jets out of a linear array. Another approach to banding, taught by U.S. Patent 5,239,312 to Merna et al., involves altering the spacing between jets on a print head. Both of these previous methods involve additional manufacturing costs in aligning the ink jets into a non-uniform pattern.

Another approach to addressing banding problems is "multipass" printing, where the printing medius is advanced at a fractional increment of the

vertical swath width, such that two or more jets of the same color pass over a pixel row on subsequent passes. The first jet will only print a portion of the dots on that pixel row, with remaining dots on the pixel row printed on subsequent passes. Multipass printing tends to mask paper advance errors such that they do not appear as discreet artifacts in the print output. However, multipass printing requires significantly more time to perform a given print job over single pass printing, and would be unacceptable for large format printing.

It is common to provide a heated platen in hot melt ink jet printers to permit the ink to solidify more slowly to thereby slightly spread on the medium. However, heat from the platen changes the moisture content of fibrous printing media, such as paper, causing non-uniform shrinkage of the fibers and generating waves or ripples in the medium, known as cockles. Heat from the platen also causes an undesirable thermal expansion of film media, such as a transparent Mylar.

It will be appreciated to those skilled in the art that numerous obstacles must be overcome to successfully produce a graphics-quality, large-format ink jet printer, such as a printer capable of printing large format media at high print rates and graphics-quality resolutions, without introducing unacceptable banding. Among the obstacles are the necessity to provide large numbers of ink jets for each color and the ability to deliver adequate quantities of ink to the ink jets during printing, the need to accurately position the ink jets horizontally with respect to each other and vertically with respect to the printing medium, and the need to accurately advance the printing medium and provide post-printing operation on the medium while avoiding cockling and thermal expansion of the medium.

Prior ink jet head configurations encountered problems with the mounting of the print head for accurate placement and movement across the printed image. The rail structure for the print head must adequately support the print head not only over the entire printed image, but also for any cleaning, maintenance and other auxiliary functions of the print head. Most prior ink jet

printers over about 17 inches wide employ either a two-rail structure, or a single-rail and outrigger structure, for head carriage X-directional travel. Both of these techniques provide two separate and independently adjustable support points for the carriage. Multiple support systems were used on wide printers because it was believed that a single rail could not provide adequate support and stability for the print head over a large distance. Multiple support systems were utilized to provide a wider support base for the print head and carriage to lessen the effect of any stability problems, as well as to provide additional strength to lessen rail flexing problems.

However, dual support systems are not altogether feasible for graphics quality, large format printing because it is difficult to maintain parallelism of the supports across the entire width of the large format media. More particularly, each support introduces positional error, resulting in non-parallel guide paths for the carriage. Further, prior art two-rail systems employ a pair of circular rails, with the print head mounted on a carriage which is in turn mounted on the rails. The carriage is generally supported by circular sets of ball bearings wrapped around each of the circular rails. Non-parallelism of the rails introduces vibration through the ball bearings to the carriage, often causing instantaneous horizontal velocity errors. If the supports are not parallel, the rollers on the carriage will bind or have excess freedom at particular locations along the rails, and cause further stability problems. If bending of the rails occurs and the railings are not maintained completely straight, errors occur in positioning the print head. Additional problems occur due to the space that the rails take up and interfering with the transfer of electronics and ink from the printer housing to the print head. It will be appreciated that these problems are magnified as the length of the rail or rails becomes greater, as in large-format printing.

It is common to provide a zone, away from the printing medium within which to "park" the print head to perform auxiliary functions. These auxiliary functions may include cutting of the paper, manipulating ink supply,

loading of the paper, certain calibration functions and cleaning of the print head. To accommodate the park zone, the support system, or rails, must support the head over a distance greater than the width of the printing medium. For example, printers handing printing medium about 11 inches wide (which accommodates the length of standard 8½ x 11 paper) may have rails about 17 inches long.

In prior ink jet configurations, the weight of the print head and carriage may cause rail bending or flexing and similar support problems. This problem is further complicated because the rails must allow the print head full range of motion, and thus can only be attached to the printer body at the rail ends. Vibration problems may occur if the print head undergoes movement with respect to the rail structure. The print head may slightly rotate or shake about an axis parallel to the rails, causing the print head placement with regard to the paper surface to be inaccurate. Alternatively, the print head may slightly rotate or shake from side to side on the rails, perhaps due to the direction of print head travel. Side to side rotation causes the saber angle to slightly change, altering the placement of ink dots.

Prior ink delivery systems for ink jet printers operate on the principle that a secondary on-head ink reservoir contains an adequate volume of ink to print the entire document. Hence, when the secondary on-head reservoir becomes empty or near empty, the print operation is halted while the ink in the secondary on-head reservoir is replenished from the main supply. Ordinarily, the replenishing of the on-head reservoir is accomplished before the start of a print operation so that the print process does not need to be halted for replenishment of the on-head reservoirs during a print operation. Halting of the print operation to replenish on-head ink reservoirs introduces delays in the print operation and the throughput of the process, and may adversely affect the quality of the print image, particularly in documents produced by aqueous ink jet printers and hot melt ink jet printers having heated platens. In aqueous ink jet printers, image deterioration is caused by the later application of aqueous ink to the now-dried

ink on the medium. In hot melt ink jet systems having heated platens, the application of heat to the medium during the period of the halt and replenishment causes additional cockling of the fibrous medium or thermal distortion of the film medium to adversely affect the image.

Current ink delivery systems also lack the ability to supply ink to the ink jet heads at a rate sufficient to accommodate high print rate large format printing, particularly for high resolution, graphics-quality output, where more ink is used on a given document. It would not be practical to modify a current ink delivery system, such as used in small-format printers, by expanding the volume of the on-head ink reservoirs to accommodate graphics-quality, large-format printing because the on-head reservoirs would be so large as to unacceptably add to the weight of the head assembly on the rail(s). If the system were designed to halt printing and replenish the on-head reservoir ink supply during the printing of the document, unacceptable delays would result in the printing operation and the quality of the print image would be adversely affected.

Because of the limitations discussed above, current printers are not capable of printing graphics quality large-format color images. Currently, only expensive electrostatic printers have exceeded 36 inch wide graphics quality printing. Graphics quality aqueous ink printers have not exceeded 36 inch wide printing, and graphics quality hot melt ink jet printers have not exceeded 24 inch wide printing. Large-format ink jet printing has been accomplished, but only at low resolution (i.e., 6 to 12 dpi). Other problems which are a barrier to large format 300 dpi color printing include the inability of existing printers to supply sufficient quantities of ink to the head without halting print operations.

SUMMARY OF THE INVENTION

The present invention is a graphics quality large-format ink jet printer. In one form of the invention, the printer is a hot melt ink jet printer capable of printing on 54 inch wide media at a minimum resolution of 300 dots per inch.

One aspect of the present invention includes an ink delivery

system for delivering ink to an ink jet head which applies ink to a print medium. The ink delivery system includes an off-head reservoir for receiving and storing a supply of ink. An on-head reservoir receives ink from the off-head reservoir during the print operation and stores the ink for delivery to the ink jet head. A controller controls delivery of ink to the on-head reservoir during the print operation. Preferably, the ink delivery system includes first and second off-head reservoirs arranged so that the first off-head reservoir receives a supply of ink in the form of a puck of hot melt ink. The controller controls the melting of the ink and the delivery of the fluid ink to the second off-head reservoir. The controller also controls delivery of the fluid ink to the on-head reservoir during the print operation.

In accordance with another aspect of the invention, an ink profiler, in the form of a memory, provides data indicative of chromatic characteristics associated with the ink supply. The controller is connected to the ink profiler and is responsive to the data contained therein to control delivery of ink from the first off-head reservoir to the second off-head reservoir. Preferably, the data includes information concerning the capacity and other characteristics of the ink supply. The profiler is a read/write memory capable of recording data concerning the amount of ink remaining in the first off-head reservoir upon completion of a print operation.

In preferred embodiments, the controller controls operation of the ink delivery system so that the second off-head reservoir does not receive the supply of ink from the first off-head reservoir if the chromatic characteristics associated with the supply of ink are not substantially the same as predetermined chromatic characteristics or if the capacity of the second off-head reservoir will not accommodate the ink from the first off-head reservoir. In other preferred embodiments, the ink delivery system of the present invention includes a level sensor for determining the level of ink in the second off-head reservoir. The sensed level of ink in the second off-head reservoir is indicative of a capacity of the second off-head reservoir to receive ink from the first off-head reservoir

without overflowing. In these preferred embodiments, the controller further controls operation of the ink delivery system so that the second off-head reservoir does not receive the supply of ink from the first off-head reservoir if the second off-head reservoir does not have sufficient volume to receive the supply of ink.

In other preferred embodiments, the ink delivery system includes a drain permitting draining the off-head reservoir of ink without expelling that ink through the ink jets.

In yet other preferred embodiments, a pump is employed to pump ink from the second off-head reservoir to the on-head reservoir. A check valve between the second off-head reservoir and the pump blocks ink from backing up from the pump to the second off-head reservoir. Preferably, a relief valve permits ink to flow back from the pump to the second off-head reservoir in the event supply tubes become obstructed. Also preferably, a continuity monitor monitors the continuity of the supply and drain tubes.

Further embodiments of the present invention relate to handling of various types of large format printing medium so that appropriate control sequence of the printing medium does not introduce artifacts into the printed image. For ink jet printers using hot melt ink, a post-imaging heating step to suitably resolve the image into the printing medium is taught. A further embodiment involves use of second print head to increase speed and coverage area. This embodiment teaches a variety of configurations to the location of discrete ink jets within each respective printing head, as well as a variety of head control solutions to increase the accuracy and consistency of the final output from the printer.

These and other embodiments of the present invention, as taught herein, combine and thereby contribute to the high speed, large format ink jet printer of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the printer apparatus of the present

invention.

FIG. 2 is a side view of the ink jet printer of FIG. 1, showing the print head configuration in place, taken in the negative x-direction.

FIG. 3 is a fragmentary elevational view of the print head configuration of the present invention, taken in the negative z-direction.

FIG. 4 is an enlarged side view of the portion of the print head configuration supported by the moving carriage.

FIG. 5 is a greatly enlarged view of a portion of the print jets on the print head configuration taken from area 5 on FIG. 3.

FIG. 6 is a greatly enlarged view of pixel targets on a printing medium during a first pass using the print head configuration.

FIG. 7 is a greatly enlarged view of pixel targets on a printing medium during a second pass using the print head configuration.

FIGS. 8A-F are a schematic representation of pixel row printing using a simplified print head.

FIG. 8G is a schematic representation of pixel row printing using the simplified print head with an alternate paper advance pattern.

FIG. 8H is a schematic representation of pixel row printing using the simplified print head with a second alternate paper advance pattern. FIG. 9 is a schematic representation of pixel row printing using an alternate simplified print head.

FIG. 10 is a schematic representation of pixel row printing using a second alternate simplified print head.

FIG. 11 is a schematic representation of pixel row printing using the print head configuration of FIGS 5-7.

FIG. 12 is an elevational view similar to FIG. 3 of an alternate print head configuration, taken in the negative z-direction.

FIG. 13 is an enlarged calibration pattern for the print head configuration.

FIG. 14 is a enlarged perspective/cross-sectional view of the rail

system of the print head configuration of the present invention in the negative x direction.

FIG. 15 is a perspective, exploded view of the blotter assembly of the present invention.

FIG. 16 is an exploded cross-sectional side view of the blotter assembly of the present invention.

FIG. 17 depicts the blotter assembly of FIG. 17 in assembled, actuated (wiping) condition.

FIG. 18 is a greatly enlarged plan view of a portion of an encoder strip.

FIG. 19 is a graphical representation of the signal produced by a dual encoder strip reader moving from left to right, as a function of the x-location of each optical sensor.

FIG. 20 is a graphical representation of the signal of FIG. 19, shown as a function of time.

FIG. 21 is a greatly enlarged plan view of a portion of an encoder strip.

FIG. 22 is a graphical representation of the signal produced by the dual encoder strip reader moving from right to left, as a function of the x-location of each optical sensor.

FIG. 23 is a graphical representation of the signal of FIG. 22. shown as a function of time.

FIG. 24 is a flow chart indicative of how a locational signal such as from an encoder strip reader is manipulated into an adjusted fire pulse in accordance with the present invention.

FIG. 25 is a side view of the ink jet printer of FIG. 1 showing the printing medium during a post-heating operation.

FIG. 26 is a schematic view of the paper tensioning apparatus of the present invention.

FIG. 27 is a fragmented view of a post-heater adjustment

apparatus of the present invention.

FIG. 28 is a perspective view of the ink supply system of the present invention.

FIG. 29 is a sectional view of the ink supply system taken along line A-A of FIG. 35, portions thereof are shown in full.

FIG. 30 is a fragmentary detail of an ink profiler docking station shown in perspective with portions of a profiler module shown in phantom.

FIG. 31 is a circuit diagram of a verification/control circuit for preventing ink from being pumped to disconnected supply tubes.

FIG. 32 is a block diagram of a control system for controlling operation of the printer, particularly the ink handling system.

FIGs. 33-35 are diagrammatic views of an alternate ink supply system in accordance with the present invention which is adapted for supplying alternate types of inks.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows an overall perspective view of printer 10. Printer 10 is a hot melt ink jet printer capable of printing at a minimum resolution of 300 dpi on 54 inch wide printing medium. As shown in FIG. 1, printer 10 includes stand 12 and housing 14. Stand 12 includes adjustable feet 16 for ease in leveling printer 10. Housing 14 includes control pad 18, and cover 20. Cover 20 may be removable for access to the internal components, or may be transparent in part to allow viewing of the printing operation. Workers skilled in the art will appreciate that various structures can be used to house printer 10 and the internal components therein. Internal to housing 14, (as shown by the broken out segment of FIG. 1), printer 10 includes paper handling system 22, ink supply system 24 and print head system 26 to print on paper or printing medium 28. To simplify the description herein, printing medium 28 will be referred to as paper 28, but workers skilled in the art will appreciated that the printing medium can be any substance capable of receiving ink printing, including paper, film (e.g:, Mylar), plastic, foil, cloth, vinyl, canvass, etc.

FIG. 2 shows a broad side view of these various paper handling 22, ink supply 24 and print head 26 systems. As indicated by directional reference 27, these internal systems generally operate at an angle relative to vertical. X, Y and Z axes are shown, with print head travel occurring along the X-axis, paper 28 travel occurring perpendicular to the X-axis and along the Y-axis, and the Z-axis being defined perpendicular to both the X-axis and the Y-axis. Printing can occur in any directional orientation of printer 10, but the orientation shown by directional reference 27 is preferred both for gravitational effects and for permitting viewing of the printing operation. As shown, the x-y plane is preferably disposed at an angle of 10 to 30 degrees to vertical.

As best seen in FIG. 2, paper handling system 22 begins with supply spool 30 for holding paper supply roll 32 and ends with paper take-up spool 34. Paper handling system 22 includes a drive motor (not shown) which rotates a plurality of drive rollers 36 and a corresponding plurality of pinch rollers 38. The drive motor is preferably a servo-motor having a rotary position feedback encoder to provide fast and accurate mechanical positioning. Guide panel 40, platen 42, nip roller plate 44 and medium heater 46 further serve to properly handle paper 28. Paper handling system 22 is described in greater detail in the PAPER HANDLING SYSTEM section below. As best shown in FIG. 1, ink supply system 24 includes ink profiler 48, four individual upper reservoirs 50A-50D and lower reservoir assembly 52. Lower reservoir assembly 52 includes four individual lower reservoirs (not individually shown). Ink profiler 48 and ink reservoirs 50, 52 may be supported on horizontal shelf 54 or on housing 14. Ink supply system 24 includes further transport and treatment apparatus (not shown) to properly provide ink to print head system 26. Ink supply system 24 is described in greater detail in the INK SUPPLY SYSTEM section below.

Print head system 26 includes carriage assembly 60 (shown in FIGS. 2-4), rail assembly 62 (FIGS. 2 and 14) and peripherals, such as drive motor assembly 64 (FIG. 2), blotter assembly 66 (shown in FIGS. 15-17) and

encoder assembly 68 (FIG. 2). Carriage assembly 60 is mounted to drive belt 70 at mount 72, and drive belt 70 is driven by drive motor assembly 64. As shown by arrows 74 (FIG. 3), carriage assembly 60 is propelled back and forth (i.e., in the positive and negative x-directions) along rail assembly 62 by drive motor 64 and drive belt 70. Workers skilled in the art will appreciate that drive motor assembly 64 can be designed to appropriately control travel of carriage assembly 60. In the embodiment shown, drive belt 70 runs in a full loop in the x-direction and includes return belt segment 76. Good acceleration, deceleration and accuracy characteristics of drive motor 64 and drive belt 70 are important for adequate printing performance. The x-direction length of travel of carriage assembly 60 and drive belt 70 must be sufficient to transport carriage assembly 60 across the entire medium width, as well as to any peripherals which may be mounted off to the side of paper 28. An umbilical assembly (not shown) is connected between carriage assembly 60 and printer 10 to provide carriage assembly 60 with ink and electrical signal supplies.

Referring now to FIG. 3, carriage assembly 60 is shown as viewed from paper 28 (i.e., in the negative z-direction). Carriage assembly 60 preferably includes two printer heads 84, 86 mounted on carriage 88. Carriage 88 is mounted to rail 82 by rollers 90. Each of rollers 90 is attached to carriage 88 by bolt 92. As described above, drive belt 70 transports carriage assembly 60 back and forth in the positive and negative x-directions as shown by arrows 74.

Each printer head 84, 86 has an array or line of jets 94 across print face 96, each line 94 including 96 individual jets 98 (shown individually in FIG. 5). Ink jets 98 are preferably those shown in U.S. Patent 5,265,315 to Hoisington et al., but may be of any type known in the art and having comparable spacing. The first 48 jets on printer head 84 are devoted to black and the following 48 jets in line 94 devoted to yellow. The other printer head 86 is similarly configured, with the first 48 jets devoted to cyan and the following 48 jets devoted to magenta. Other than being supplied by different ink colors, the two printer heads 84, 86 are substantially identical. Each printer head

84, 86 includes an ink supply structure 100 containing on-head ink reservoirs for at least two respective colors of ink, and a ribbon cable connector 102.

Encoder strip reader 104 is also mounted on carriage 88. As shown in FIG. 2, encoder strip 106 is held in encoder strip tensioner 108. Encoder strip tensioner 108 and encoder strip 106 run the entire length of travel for carriage assembly 60. Encoder strip 106 is preferably a mylar strip photographically etched at 150.5 line pairs per inch. After this original etching. encoder strip 106 may then be appropriately tensioned and secured in encoder strip tensioner 108 to accurately position 301 line pairs per inch along the length of travel for carriage assembly 60. Encoder strip reader 104 can optically read encoder strip 106. With simple data manipulation of the output from encoder strip reader 104, the exact x-position of printer heads 84, 86 and jets 98 thereon can be known. It is preferable to mount encoder strip reader 104 and encoder strip 106 as close as possible to jets 98, and thereby minimize any positioning inaccuracies between these points.

Figure 4 depicts an enlarged side view of the portion of FIG. 2 showing carriage assembly 60. Print face 96 with piezoelectric jets 98 (shown individually in FIG. 5) therein should be positioned for placement immediately opposite paper 28. Ink supply structure 100 includes heater cartridge 110 and heater plate 112 for heating the ink within reservoir 114. Lung 115 is provided on printer heads 84, 86 for proper de-aeration treatment of the ink. To the rear of ink reservoir 114, alignment pins 116 and thermal standoffs 118 separate heated ink reservoir 114 from printer carriage 88. Umbilical connections 120 are provided to readily attach and detach the umbilical (not shown) with ink flow to printer heads 84, 86.

Electronic circuitry 122 is provided on printer head 84, 86 to control piezoelectric jets 98, and a further circuit board 123 is provided to the outside of carriage 88. Ribbon cable connector 102 allows electronic communication to be readily attached and detached between the umbilical (not shown) and printer heads 84, 86 via a ribbon cable (not shown). The umbilical

(not shown) thus connects electronic circuitry 122 and circuit board 123 and an external controller (not shown) for the entire system. All of this structure is mounted on mounting block 124 which rides on carriage 88. Heat sink 126 is disposed on the outside of circuit board 123 to aid in cooling circuit board 123.

During operation of printer 10, printer heads 84, 86 print both when traveling in the positive x-direction and when traveling in the negative x direction. After each pass of carriage assembly 60 (i.e., regardless of carriage assembly direction), paper handling system 22 advances paper 28 in the y-direction. Print head system 26 is described below in greater detail below in the HEAD CONTROL SYSTEM section.

I. HEAD CONTROL SYSTEM

As can be best seen from inspection of FIG. 3, line 94 is canted with respect to printer head 84 at the prior art 7.125° angle 128. Under the previous arrangement, printer head 84 would be mounted square in comparison to the x-direction of travel 74, and the saber angle (e.g. the angle that the line of jets makes with respect to the x-direction of printer head travel) would be 7.125°. The present print head configuration does not mount printer heads 84, 86 square, but rather mounts printer heads 84, 86 at an angle 130 with regard to carriage assembly 60. In one embodiment, the angle 130 is 22.62°, and the addition of these two angles 128, 130 creates saber angle 132 for printer heads 84, 86 of 29.745°.

This saber angle, together with spacing between jets of approximately 0.027 inches, leads to vertical spacing of adjacent jets at 4/300ths of an inch (i.e., 4 pixels) and horizontal spacing at 7/300ths of an inch (i.e. 7 pixels). This 7 to 4 relationship, rather that the previous 8 to 1 relationship, means that only one out of every four rows of pixels will be printed for each pass of carriage assembly 60. Various methods may be used to adjust to printing on every row of pixels from the four row per pass spacing, including the variable paper feed interlacing described below. The width of the print stroke (for the same number of jets) is four times as wide as previous print heads. The 7 to 4

relationship further allows printer heads 84, 86 to remain as compact as feasible under present manufacturing and ink supply conditions.

Workers skilled in the art will recognize that there are many ways to mount jets 98 and printer heads 84, 86 to arrive at an identical or similar saber angle 132. For instance, jets 98 could merely be arranged on a print head at an angle between 29 and 30 degrees to the print head, and the print head mounted square to the x-direction of print head travel. The particular mounting system used is not important to the invention described herein, and a worker skilled in the art may choose any system of mounting which proves beneficial to his or her situation and/or effects the same result.

FIG. 5 depicts a greatly enlarged view of a portion of line 94 of jets 98. To describe the effects of a paper advance, we have numbered the jets 98 (only jets 1-15 are shown in FIG. 5). Jets 98 are aligned with uniform spacing 134 between adjacent jets 98. With the print head mounting previously described, each jet 98 is offset with an x-component 136 of seven pixels (i.e., 7/300ths of an inch, or 0.023 inches) and a y-component 138 of four pixels (i.e., 4/300ths of an inch, or 0.013 inches) from adjacent jets 98. This leads to the 29.745° saber angle 132. Each color of ink on the print head 84 has a similarly situated line 94 of jets 98.

In the alternate preferred embodiment shown in FIG. 3, printer heads 84, 86 are mounted at an angle 130 of 6.911° with regard to carriage assembly 60. The addition of this angle 130 with the prior art 7.125° angle creates saber angle 132 for printer heads 84, 86 of 14.036°. This places each jet 98 a horizontal distance of 0.0265 inches and a vertical distance of 0.0066 away from the adjacent jets 98, and allows square pixel printing of 306.84 dpi in both the horizontal and vertical directions.

FIG. 6 shows a greatly enlarged section of paper 28 during a first pass of printer head 84. Present locations of jets 1 and 2 are shown in a dashed line 98, and during this first pass printer head 84 is traveling from right to left with respect to paper 28, as shown by arrow 74A. Jet 1 has passed over a line

of targets or pixels 142, making up pixel row 142. Each of these targets 142 is one pixel apart. Jet 2 has similarly passed over a line of pixels 144 spaced one pixel apart horizontally making up pixel row 144. Because the jets are spaced four pixels apart in the y-direction as shown by y-component offset 138, pixel rows 142, 144 are spaced four pixels apart.

It should be understood that pixels 142, 144 are potential targets for an ink jet 98, and not necessarily dots of ink on the printing medium. The actual dots of ink deposited by jets 98 may have a uniform size substantially larger than the targets 142, 144 depicted, or may have a size which varies from dot to dot. Additionally, ink dots are not generally placed at every pixel 142, 144. The amount of ink, the color or color combination of ink, and whether ink is to be placed at all are determined by software to accurately reproduce a full color image.

After the first pass is complete, paper 28 is advanced 47 pixels downward. FIG. 7 shows the same area of paper as FIG. 6 during a second pass of printer head 84. Printer head 84 is moving from left to right during this second pass, as shown by arrow 74B. The full pixel rows 142, 144 (representing whatever ink dots have been deposited there), are shown. After a 47 pixel paper advance, jet 13 (12 jets/48 pixels below jet 1 on printer head 84) is one pixel below pixel row 142. Jet 13 passes over pixel row 146. Similarly, jet 14 is one pixel below pixel row 144, and passes over pixel row 148. After two additional passes, the entire pattern of potential pixel targets have been covered by jets 98.

As will be described below, various sequences of variable paper advance can be used. In one embodiment, a paper advance series of 49, 49, 45 and 49 pixels will position printer head 84 at a location which is a full print stroke (192 pixels) beneath the first pass, having covered the entire pattern of potential pixel targets. Larger images are reproduced merely by continuing out the pixel target array through more passes of printer head 84. The paper advance continues at 49, 49, 45 and 49 pixels until the end of the image.

The disclosed print head and variable paper advance configuration

has several advantages over the prior art which can be shown through schematic diagrams of simpler arrangements embodying individual features of the present invention. For simplicity, the example above and these schematics are explained for only a single color, however it is understood that an identical procedure may be utilized for additional colors to be laid down on paper 28. Throughout schematic FIGS. 8A-11, column 150 indicates pixel row addresses in an image. Column 152 indicates which pass of the print head the pixel row is printed on. Column 154 indicates which jet of the print head passes over a particular pixel row. Workers skilled in the art will appreciate that the orientation of the image and the numbering of the jets may be altered without changing the overall effect of the invention or the importance thereof. The numbering of jets, passes and pixels rows in these examples is for illustration purposes only.

FIGS. 8A-F represent a schematic representation of pixel row printing using a simplified print head. The simplified print head has four jets (n = 4) which are each spaced a uniform Y-component of four pixels apart from adjacent jets (s = 4). The image represented in FIGS. 8A-F has 36 pixels in the Y-direction, and can be as wide in the X-direction as permitted by the length of travel of the print head. As represented by FIG. 8A, the paper is advanced until the bottom of the image begins to pass underneath the print stroke, thus the first pass of the print head places jets 1 and 2 over the very bottom of the image to be printed. With the direction of paper feed, it is to be understood that the bottom portion of an image is printed prior to continuing up in printing higher pixel rows. Jet 1 prints pixel row 32, while jet 2, 4 pixels below jet 1, prints pixel row 36.

FIG. 8B represents a second pass of the print head after the paper has been advanced 5 pixels. This paper advance has placed jet 1 over pixel row 27, jet 2 over pixel row 31, and jet 3 over pixel row 35.

FIG. 8C represents a third pass of the print head after the paper has been advanced another 2 pixels. Each of the jets 1, 2 and 3 are located 2 pixels higher on the image than during the preceding pass.

FIG. 8D represents the printing image during a fourth pass of the print head after the paper has been advanced another 3 pixels. It is not until this fourth pass of the print head that jet 4 is actually located over the printed image. The 3 pixel paper advance has placed jet 4 over pixel row 34, thus completing the lowest portion of the image.

FIG. 8E represents a fifth pass of the print head after a 6 pixel paper advance.

FIG. 8F represents the image after the entire image has been printed. The series of paper advances, 5/2/3/6 pixels respectively, has completely filed in the image. The identical series of advance may be repeated continually to print an image of any size in the Y-direction.

The schematic of FIG. 8F readily shows both the series of advance (d_1 = 5, d_2 = 2, d_3 = 3, d_4 = 6) by identifying the location of jet 1 during consecutive passes of the print head. FIG. 8F also readily shows the spacing between jets (s = 4) and the number of jets (n = 4) by identifying the location of each jet during a particular pass of the print head, (in this case, pass 8). Review of FIG. 8F will reveal that the spacing between jets and the number of jets is constant and uniform through printing of the image, and the entire image is printed merely by altering the distance of paper feed (d).

It will be recognized that the paper advance series continually repeats itself, such that any of the advances may be selected as d_1. In the case of FIG. 8F, while we have selected d_1 = 5 as the first advance in the series, d_1 could be any of the advances of 2, 3 or 6 pixels. It should also be recognized that the order of paper advances is not necessarily exclusive. In the case of FIG. 8F, the paper advances could be 5, 6, 3 and 2 pixels with the same result.

FIG. 8G is a schematic representation of pixel row printing similar to FIGS. 8A-F, but using a different paper advance. In this alternative paper advance, (d_1 = 5, d_2 = 5, d_3 = 5, d_4 = 1). The alternative paper advance pattern of FIG. 8G also covers the entire image without any two jets passing over the same pixel row. However, the paper advance pattern of FIG. 8G is slightly less beneficial

than the paper advance pattern of FIG. 8A-F. Because the fourth paper advance in FIG. 8G is only one pixel, several adjacent pixel rows are printing by the same jet (rows 4 and 5; 8 and 9; 12 and 13; 16 and 17, 20 and 21; 24 and 25; 28 and 29; 32 and 33). This provides a higher chance that a viewer might detect a paper advance error about these rows.

FIG. 8H represents a third paper advance pattern using the same simplified print head. In FIG. 8H, ($d_1 = 3$, $d_2 = 3$, $d_3 = 3$, $d_4 = 7$). This paper advance pattern avoids having any two adjacent pixel rows being laid down by the same jet, and further has relatively uniform paper advances.

Additional modified series of paper advance could also prove useful with the simplified print head configuration represented in FIG. 8A-H. The preferred paper advance series taught by this invention have some common similarities:

(1) Each of the paper advance series totals 16 pixels ($d_1 + d_2 + d_3 + d_4 = 16$), which is the number of jets times the spacing between jets ($n \times s = 16$). Accordingly, one total series of advance will progress through one entire print stroke.

(2) Each of the paper advance series includes four advances, which is equal to the spacing between jets ($s = 4$).

(3) For each advance, the total advance provided so far by the series, divided by the number of jets, provides a different remainder. For instance with the paper advance pattern of FIG. 8F of 5/2/3/6 pixel steps:

$d_1/n = 5/4$ (remainder of 1);

$(d_1 + d_2)/n = 7/4$ (remainder of 3);

$(d_1 + d_2 + d_3)/n = 10/4$ (remainder of 2); and

$(d_1 + d_2 + d_3 + d_4)/n = 16/4$ (remainder of 0).

Any series of advance which will fulfill these commonalities will allow the image to be totally covered without any two jets covering the same pixel row. Workers skilled in the art will appreciate that various series of paper advance will accommodate these commonalities. Workers skilled in the art will further

appreciate that these commonalities should be modified based on the print head structure used and the desired goal sought, and that it is not essential to incorporate all the suggestions herein to practice the claimed invention.

FIG. 9 is a schematic representation of pixel row printing using a different simplified print head. The print head represented in FIG. 9 has three jets ($n = 3$) with the Y-spacing between jets being only 3 pixels ($s = 3$). The pattern of advance, 2/2/5 pixels will appropriately fill in the entire image without having any two jets pass over the same pixel row.

FIG. 10 is a schematic representation of pixel row printing with variable paper advance, with the print head having four jets ($n = 4$) at 3 pixel spacing ($s = 3$). In this case, a series of advance of 5/5/2 pixels suitably covers the image.

FIG. 11 is a schematic representation of pixel row printing using the print head configuration shown in FIGS. 5-7. The jets have been numbered 1-48, with 1 being the upper left jet on the print head and 48 extending through the lower right jet of a particular color on the print head. There are 48 jets of each color ($n = 48$) and the spacing between jets equals 4 pixels ($s = 4$). The paper advance sequence is ($d_1 = 49$, $d_2 = 49$, $d_3 = 45$, $d_4 = 49$). The paper is advancing at approximately 48 pixels per advance, or one-fourth of the print stroke, and accordingly during the first pass only jets 1-12 are located over the image. Because the jets are evenly spaced, four vertical pixels apart, jets 1-12 are targeted at every four pixels rows 193, 197, 201... 233, 237 (i.e., $189 + 4j$). After the first print head scan, the printing medium is advanced 49 pixels. This locates the first jet over pixel row 144 ($193 - 49 = 144$). Accordingly, the second pass of the print head, traveling in the negative x direction, locates jets 1-24 over pixel rows ($140 + 4j$). By advancing the paper subsequent advances $d_2 = 49$, $d_3 = 45$, and $d_4 = 49$, it can be seen that the present print head configuration will place the uniformly spaced print jets over each pixel on the image once and only once. By repeating the printing medium advance sequence of 49, 49, 45 and 49 pixels, a print head image of any size may be obtained

while maintaining full efficiency of the print head. Each pixel location being covered once and only once, with no jets going unused while passing over the image.

The schematic of FIG. 11 represents an image having 240 pixel rows. As the preferred pixel spacing is 300 pixels per inch, this represents a vertical image having a height of only 4/5th of an inch. The preferred embodiment printer head 84 has a single color print stroke width of 192 pixels (48 jets × 4 pixels spacing/jet = 192 pixels). The schematic of FIG. 11 accordingly represents 1.25 times the width of one print stroke, even though 8 passes were required for full coverage.

This paper advance sequence, together with the 7 to 4 relationship between jets, provides a number of advantages. Firstly, because the print stroke is four times as wide as compared to previous saber angles and covers an area through four passes, any error caused by slight variations in paper advance are averaged over a wide section of print, rather than occurring as discreet edges between solid printer strokes. Because any error in paper advance now occurs across of wide range of pixels, rather than between two uniform arrays of pixels, any positioning errors are much less visually perceptible. Because each area of the page is covered by four printer strokes, distinctions due to an inaccurate paper advance mechanism are largely hidden.

Secondly, each pixel row is printed in an opposite direction as adjacent pixel rows. The opposite direction of adjacent pixel rows can be verified in FIG. 11 by noting that the pass number for consecutive pixel rows alternates between odd (i.e. passes in one direction) and even (i.e., passes in the other direction). The opposite directions of adjacent pixel rows makes any directional banding problems (such as direction dependent ink dot shapes, ink mixing non-homogeneity, and differing order of ink lay down) occur at a very high frequency, making such problems difficult to visually perceive.

Thirdly, each printed pixel location is separated four vertical locations away from other pixel rows currently being printed. This allows for

substantial dissipation of thermal effects through the intermediate three open pixel locations to reduce or eliminate thermal banding problems. Adjacent pixel rows have entirely solidified prior to printing intermediate pixel rows. Having adjacent jets print pixel rows which are four pixels apart further averages problems with the paper advance across a high frequency area of the paper rather then creating low frequency distinct edges.

Fourthly, each of the steps are relatively uniform. With the sequence of 49, 49, 45 and 49 pixels, each of the steps are within 3 pixels of the number of jets, and three of the four steps are within 1 pixel of the number of jets. The more uniform paper advance pattern tends to better hide any banding problems occurring therein. Inaccurate paper advance characteristics which may be caused by stretching, tensioning or other considerations are lessened or avoided. By advancing the paper at a relatively uniform step advance, the paper is similarly tensioned or stretched during the printing of each pixel row.

Finally, pixels rows printed by the same jet are spaced approximately 1/6th of an inch apart. The separation between pixel rows printed by the same jet tends to further provide somewhat of a soft brush effect rather than distinct differences between segments of the paper of the printed image, and particularly helps to hide problems of a single jet getting clogged or failing intermittently.

In an alternative preferred embodiment, with jets 98 arranged at a 14.036° saber angle, a repeating paper advance sequence of 47, 49 pixels is used. This pattern takes full advantage of the second, forth and fifth benefits discussed above, and partial advantage of the first and third benefits. The print stroke is twice as wide as compared to previous saber angles and covers an area through two passes, allowing some averaging of slight variations in paper advance and avoiding discreet edges between solid printer strokes. Each printed pixel location is separated two vertical locations away from other pixel rows currently being printed. This allows for dissipation of thermal effects through the intermediate open pixel location to reduce or eliminate thermal banding

problems.

The printer 10 of the present invention allows for a significantly higher rate of printing than previously possible. By using multiple printer heads such as the two printer heads 84, 86 and two colors per head shown, the capacity of on-head ink reservoir 114 (see FIG. 2 and 4) has been increased to 7-10 cc per color of ink. With the various ink handling and electronic transfer rates used, the dual-head system of the preferred embodiment of the present invention can achieve a 16 kilohertz drop rate (i.e., 16,000 firings per ink jet per second). With 48 jets 98 per color at this 16 kilohertz drop rate, printer 10 can print in excess of 3.0 million dots per second, for an average full color printing rate of about 512 in^2 per minute at the minimum resolution of 300 dpi. The dual heads 84, 86 retain a stroke width which is narrower than if all 192 jets 98 were aligned sequentially on a single head. The dual heads 84, 86 can be separately oriented on carriage assembly 60, and thus lines of jets 98 can be separately oriented with respect to each other.

However, multi-head printing creates problems for bi-directional printing due to a differing order of ink laydown. With the carriage assembly 60 shown in FIG. 3, black and yellow, with black on top, are the colors on printer head 84, and cyan and magenta, with cyan on top, are the colors on printer head 86. Due to the direction of paper feed, the top colors will always be printed first on a particular pixel row, beneath the second two colors. However, the ordering of the top colors and the ordering of the bottom colors on a particular pixel row (i.e, KCYM or CKMY) is dependent upon the direction of print head travel for that pixel row. With proper interlacing techniques and with adequate mixing of ink colors, no adjustment based on the ink order may be necessary. However, the present invention contemplates several addition methods to handle changing ink laydown orders.

FIG. 12 depicts an alternative embodiment of carriage assembly 60 shown in FIG. 3. In the carriage assembly 156 shown in FIG. 12, printer head 158 has cyan ink supplied to the top 48 jets and yellow ink supplied to the

bottom 48 jets. Printer head 160 has black ink supplied to the top 48 jets and magenta ink supplied to the bottom 48 jets. Moreover, printer head 160 is mounted at a position approximately 2/3rd of an inch (i.e., 192 pixels, or the Y-spacing for 48 jets) offset from printer head 158 in the Y-direction, as shown by offset 162. By mounting printer head 160 this distance and number of jets below printer head 158, cyan is always printed first and magenta is always printed last, regardless of the direction of print head travel. The order of printing is accordingly reduced to either CKYM or CYKM. Yellow and black are seldom printed on the same pixel location, and this print head configuration allows for consistent color reproduction without significant problems based on the direction of print head travel.

Additionally, in either the configuration of FIG. 3 or FIG. 12, multiple printer heads may have slightly offset alignment as necessary to adjust the relative pass timing between ink colors. For instance, in the configuration of FIG. 3, printer head 86 may be aligned to be one, two or three pixels lower than printer head 84. Similarly, in the alternative embodiment shown in FIG. 12, printer head 160 may be aligned 193 pixels, 194 pixels, or 195 pixels beneath printer head 158. Because of this slightly offset printer head alignment, ink dots laid down by one printer head will not be directly over the ink dots laid down by the other printer head during the same pass. If the printer heads have no offset in alignment, there is about a 0.02 second time differential between laying down dots of different colored inks over each other (that is, the time period for carriage assembly 60 to travel the horizontal distance between printer heads 84, 86 during a pass is about 0.02 seconds). Conversely, if a slight offset is used, this relative timing is drastically altered. As the later (top) ink will be applied on a subsequent pass of the carriage assembly 60 (perhaps several passes later), the time differential may be 1-10 seconds apart. Workers skilled in the art will appreciate that the optimal alignment offset between printer heads 158, 160 is dependent upon the mixing characteristics of the ink and the way multiple colors of ink interact with each other to reflect light, and may change based on the

particular characteristics desired.

When the slight printer head offset is combined with variable advance interlacing, the timing differential and order of color laydown can be further altered. For instance, by using the configuration of FIG. 3 with a one pixel offset and 49, 49, 45, 49 pixel paper advance, three quarters of the pixel locations having both yellow and magenta will be printed with magenta over yellow, whereas only one pixel row out of every four will be printed with yellow over magenta. Similarly, three quarters of the pixel locations having both black and cyan will be printed with cyan over black, whereas only one pixel row out of every four will be printed with black over cyan. Workers skilled in the art will appreciate that the location of colors on carriage assembly 60, the printer head offset and the variable advance interlacing can be selected as desired to create the desired order of color laydown and desired timing differential between colors.

In an alternate preferred embodiment, with adjacent jets aligned 2 pixels apart in the y-direction, printer head 86 is aligned to be one pixel (i.e., 0.0033 inches) lower than printer head 84. This alignment has been noted to substantially correct thermal banding artifacts, and, correct use of variable advance interlacing reduces the color order laydown problems in bi-directional printing.

In a second alternate embodiment, with adjacent jets aligned 4 pixels apart in the y-direction, printer head 86 is aligned to be one pixel (i.e., 0.0033 inches) lower than printer head 84. A five step pattern is used for paper advance, with steps of 1, 1, 1, 1 and 188 pixels for a 48 jet per color head. During the first pass of the sequence, only printer head 84 is fired. During the last pass of the sequence, only printer head 86 is fired. With this configuration and advance sequence, each jet on printer head 86 prints over a pixel row printed by the jets on printer head 84 from the previous pass. Accordingly, the order of color laydown remains constant regardless of bi-directional printing.

Other similar series of advance could be used to the same effect,

so long as the offset between printer head 86 and printer head 84 is equivalent to one or more of the previous step size. For instance, if printer head 86 is aligned to be offset 39 pixels from printer head 84, a series of advance of 39, 39, 39, 39 and 36 pixels could be used for 48 jet per color heads with 4 pixel offsets between jets. During the first pass of the sequence, only printer head 84 is fired. During the last pass of the sequence, only printer head 86 is fired. This configuration and advance sequence would similarly have each pixel row printed by printer head 84 prior to printing by printer head 86.

Still other variable advance interlacing schemes could be used with this strategy. For instance, with a 62 pixel offset between heads, 48 jets per color, 4 pixel offsets between jets, a series of advance of 27, 35, 27, 35, 27, 41 could be used. During the first and second pass of the sequence, only printer head 84 is fired. During the last two passes of the sequence, only printer head 86 is fired. This configuration and advance sequence would have each pixel row printed by printer head 84 two passes prior to printing by printer head 86, such that the order of color laydown is uniform in bi-directional printing. This configuration and advance sequence also has relatively even, non-identical advance distances.

Finally, software may adjust the amount of the relative colors to compensate for differences in print head direction (i.e., for which color ink will be placed above), so that proper coloring of the entire image is maintained despite differing ink orders. Either the proportion of dots of a particular color laid down may be altered, or the relative size of the ink dots may be altered as desired in software to compensate appropriately. Workers skilled in the art will again appreciate that this adjustment is dependent upon the mixing and light reflection characteristics of the particular ink colors.

FIG. 13 is an enlarged calibration pattern 164 for the print head configuration. Calibration pattern 164 is used to calibrate horizontal timing of each color in relation to the other colors. A similar calibration pattern laid down in the vertical direction can be used to calibrate vertical placement of each color

in relation to the other colors.

In creating calibration pattern 164 of FIG. 13, a pattern of marks or blocks 166 of a first color (in this case black) are laid down. Each of blocks 166 has a uniform distance 168 between them. Additionally, each block 166 has a leading edge 167, a trailing edge 169, and a uniform thickness 170 between leading edge 167 and trailing edge 169. With uniform distance 168 and uniform thickness 170, both leading edges 167 and trailing edges 169 are uniformly spaced. It is preferred that blocks 166 have a thickness 176 which is equal to distance 168 between them, such that blocks 166 shade in one-half of the area along the test pattern 164. Index 172 is also printed to designate calibration settings along calibration pattern 164.

A second row of blocks 174 is printed with a subsequent color (in this case, magenta) on carriage assembly 60. Second color blocks 174 each have a uniform thickness 176 between leading edge 175 and trailing edge 177. Thickness 176 is equal to the uniform distance 168 between first color blocks 166. The spacing 178 between second color blocks 174 is slightly different than the spacing 168 between first color blocks 166. As shown, the spacing 178 is one pixel greater than spacing 168. Because of this difference in spacing, the second color blocks 174 line up with the first color blocks 166 at a single location 180. This calibration location 180 is readily identified because blocks 166, 174 completely shade this section of test pattern 164. This calibration location 180 is similarly identified as the only location wherein leading edge 175 of second color block 174 lines up with trailing edge 169 of first color block 166. The remainder of test pattern 164 has blocks 166, 174 which extend over each other so as not to completely shade pattern 164.

Alternatively, calibration pattern 164 may be printed such that the proper calibration location occurs where second color blocks 174 completely overlay first color blocks 166. In this case, the calibration location may be identified as the only location wherein leading edge 175 lines up with leading edge 169 of first color block 166, and no unshaded portion of second color block

174 is seen to either side of first color block 166.

Calibration pattern 164 can be read either by the user or by automated equipment (not shown). Automated equipment for reading calibration pattern 164 may merely determine the percentage of shading as a function of location on calibration pattern 164. Similar calibration patterns can be laid down for the calibration for the remaining colors, both vertically and horizontally. In contrast to previous calibration techniques, overlaying the calibration marks and total shading provided by the proper setting leads to a significantly easier determination of the proper calibration setting. It should be noted that blocks 166, 174 may be printed by the same printer head or by different printer heads, depending on which colors are being calibrated. It should further be noted that multiple passes of carriage assembly 60 may be required to print blocks 166, 174. Numerous jets 98 may be used in printing blocks 166, 174, as well as numerous advances of paper 28. By properly choosing the size and orientation of blocks 166, 174, calibration may be achieved between various jets 98 as well as between various paper advances.

Upon determining the proper calibration location 180 for each color (both horizontally and vertically), the calibration location 180 can then be adjusted in software to alter the firing of jets 98. For instance, if the proper calibration of the second color is 2 horizontal pixels off, the second color may be fired 2 pixel locations earlier (or later depending on the direction of print head travel) during the print head pass. Similarly, if the proper calibration of the second color is 1 vertical pixel off, the information fed to the second color jets may be modified such that they print one pixel lower within the image. The proper calibration information may further be extrapolated to make corrections amid lines of same color jets 98. In this way, for instance, the first 24 black jets may be adjusted by one pixel relative to the second 24 black jets, so as to calibrate saber angle 132 to higher accuracy.

FIG. 14 depicts a portion of rail assembly 62 in perspective view. A number of attachment bolts 182 are shown securing rail 82 to attachment plate

184. Attachment plate 184 extends a significant distance in the y-direction as shown by height 186, such that attachment plate 184 will withstand the y-direction load of carriage assembly 156 without bending. Height 186 of attachment plate 184 in the y-direction is preferably in excess of 2 inches. Z-stiffener bar 188 is welded or otherwise securely attached to attachment plate 184, and extends a significant distance in the z-direction as shown by width 190. Width 190 of z-stiffener bar 188 is preferably in excess of 2 inches. Z-stiffener bar 188 provides additional stiffness in the z-direction, such that attachment plate 184 will withstand the z-direction load of carriage assembly 60 without bending. As shown in FIG. 2, carriage assembly 60 includes four rollers 90 to attach carriage assembly 62 to rail 82 for travel in the x-direction.

Rail assembly 62 may include end flanges 78. While only one end flange 78 is shown, it is understood that rail assembly 62 includes a similar end flange 78 at its other end. End flanges 78 include bolt holes 80 for ready attachment and detachment to housing 14 by suitable fasteners such as bolts 189. Attachment plate 184 and z-stiffener bar 188 extend in the x-direction in excess of the entire length of carriage travel, and only need be supported at their ends by end flanges 78. Attachment plate 184 and z-stiffener bar 188 are both preferably of aluminum, of sufficient thickness so as not to be overly heavy but to otherwise readily support the load of carriage assembly 60 without bending.

As shown in FIG. 14, rail assembly 62 has no structure restricting end 192 of rail 82. Accordingly, carriage assembly 60 can be simply removed off end 192 or rail 82 as follows. First, flange 78 is detached from housing 14, and opposite end flange 78 is loosened from housing 14. Carriage assembly 60 is released from drive belt 70 at mount 72. The entire rail assembly 62 is slightly pivoted, allowing carriage assembly 60 to be taken directly off end 192 of rail 82 past housing 14. Alternatively, a hinge (not shown) may be used to attach plate 184 and z-stiffener bar 188 to end flange 78. Such a hinge would allow pivoting of rail assembly 62 without loosening of opposite end flange 78.

By having rail assembly 62 supported only at its ends, pivoting

of rail assembly 62 is easier and can be performed more quickly. The other end (not shown) of rail assembly 62 may be similarly configured to allow carriage assembly 60 to be taken directly off the other end of rail 82 in a like manner. This ease of removing carriage assembly 60 greatly facilitates maintenance and replacement of carriage assembly 60 and/or component parts therein. The umbilical assembly (not shown) is further readily detachable from carriage assembly 60 at ribbon cable connector 102 and umbilical connections 120 (FIG. 4), allowing carriage assembly 60 to be readily and completely removed from printer 10. Workers skilled in the art will appreciate that various alternative mounting arrangements can be used for rail assembly 62, while still allowing ready removal of carriage assembly 60 off end 192 of rail 82.

Rail 82 is rigidly attached to attachment plate 184 through attachment bolts 182. Rail 82 is too small to be supported only at its ends and still carry the load of carriage assembly 60 without bending. Accordingly, enough attachment bolts 182 are provided throughout the length of rail 82 to prevent rail 82 from bending in either the y or z-direction anywhere along its length. Rail 82 is preferably made of rolled structural steel, and further has sufficient stiffness to prevent torsional bending under the load of carriage assembly 60. Rail 82 is a minimum of 1 inch wide and 0.25 inches thick. Rail 82, as attached in this manner to attachment plate 184, is strong enough to prevent bending or misalignment of greater than .001 inches while supporting carriage assembly 60 of up to 10 lbs across an 81-inch span.

Rail 82 includes upper tread surface 194 and lower tread surface 196 on body 198. As shown in FIG. 4, rollers 90 have corresponding treads 91 which ride on tread surfaces 194, 196. As will be explained, the single rail 82 and the attachment of rollers 90 thereto allow movement of carriage assembly 60 only in the x-direction, and permit no rotational movement or vibration of carriage assembly 60.

Upper 194 and lower 196 tread surfaces should be precision machined and toleranced so as to be parallel to each other throughout the length

of rail 82. This precise parallelism prevents rollers 90 from binding or being loose anywhere along the length of rail 82. Additionally, because both upper 194 and lower 196 tread surfaces are provided on a single rail 82, problems with aligning multiple rails in parallel are avoided.

Upper tread surface 194 and lower tread surface 196 have a v-shape, and thus provide tread surfaces disposed at an angle. Tread surfaces 194, 196 accordingly provide bearing forces for rollers 90 in an axial direction (i.e., positive and negative z-direction) and a radial direction (i.e., positive and negative y-direction). As depicted in FIG. 14, tread surfaces 194, 196 are preferably disposed at 45° to the x-y plane. Providing both axial and radial bearing forces for rollers 90 could similarly be achieved by u-shaped upper and lower tread surfaces and conforming surfaces on roller treads 91, without surfaces disposed at an angle. However, v-shaped tread surfaces 194, 196 are less likely to bind or have loose sections than u-shaped tread surfaces, which would require parallelism between the outer walls of the u-shape. Because rail 82 transfers bearing forces both in axial and radial directions, the present print head configuration need only use a single rail 82 throughout the length of travel of carriage assembly 60.

As shown in FIG. 14 by offset 200, upper tread surface 194 and lower tread surface 196 should be far enough apart to counteract any torsional forces about rail 82 (i.e., about an x-axis). Accordingly, tread surfaces 194, 196 interacting with treads 91 to prevent carriage assembly 60 from rotating or vibrating about an x-axis even though only one rail 82 is provided. The rail may be constructed to be wider than rail 82 shown. For instance, the rail may be about 4 inches wide. This additional width not only provides strength against bending in the y-direction, but also separates upper and lower rollers 90 to provide a greater moment arm against rotation or vibration about an x-axis.

It is important that carriage assembly 60 be maintained in a stable position as it is moved back and forth across the image. Any rotational vibration or variation about a z-axis would temporarily alter the placement of jets 98 and

saber angle 132, causing poor printing results. This type of rotation is particularly likely to occur as the result of the quick directional changes which carriage assembly 60 undergoes as it is transported by drive belt 70. As shown in FIG. 3, rollers 90 have a significant lateral offset 202 between them. This lateral offset 202 allows rollers 90 to provide a significant moment about a z-axis and prevent any rotational movement or vibration of carriage assembly 60 about a z-axis.

It is similarly important that carriage assembly 60 be maintained a constant distance from printing media 28 and platen 42 as printing occurs. Jets 98 are designed to place uniformly sized ink dots on printing media 28 only from a particular distance. If jets 98 are too close, the ink will not be uniformly placed, or, worse yet, print face 96 may contact printing media 28 and smear ink. If jets 98 are too far, ink may similarly be non-uniform or splattered on the image. Additionally, because jets 98 are moving while ink is jetted, the distance between jets 98 and printing media 28 affects the location of ink dots. Any rotational vibration or variation about an x or a y-axis would temporarily alter the distance between jets 98 and printing media 28, causing poor printing results, as would any bending of rail 82 in the z-direction. Rollers 90 with treads 91, in combination with tread surfaces 194, 196, prevent movement of carriage assembly 60 in the z-direction. Similarly, lateral offset 202 allows treads 91 on rollers 90 to provide a significant moment about a y-axis to prevent any rotational movement or vibration of carriage assembly 60 about a y-axis.

While four rollers 90 are shown on carriage assembly 60, it will be noted that only three rollers are necessary to provide sufficient force to prevent rotation or vibration about a z-axis and/or about a y-axis. If three rollers are used, a single roller should be placed on one side of rail 82, in between two rollers placed on the other side of rail 82. Each of the rollers should be significantly offset from the other two. However, it is preferred that four rollers be used as shown in FIG. 3 to avoid the tendency for torsional bending of rail 82 and the possibility of vibrational movement about an x-axis.

Carriage assembly 60 must be constructed to be stiff enough to not allow any relative movement between rollers 90 and printer heads 84, 86. To increase stiffness between rollers 90 and carriage assembly 60, bearings for rollers 90 should be selected to allow little or no play between rollers 90 and bolts 92. Bearing free play in rollers 90 may be further reduced or eliminated by using a y-direction "pre-load". By having the distance between upper tread surface 194 and lower tread surface 196 slightly greater than the corresponding distance between treads 91 on rollers 90, rollers 90 place opposing forces on rail 82. These opposing forces, preferably from 3 to 5 lbs, help to take up bearing free play between opposing rollers 90. As with torsional force, pre-load force is better withstood by rail 82 if rollers 90 are provided in roller pairs.

The single rail 82 and attachment plate 184 system described avoids the problems of the prior art. Only one rail is used so there is no problem with parallelism between rails. The possibilities of bending of rail 82, any binding or looseness of rollers 90, and vibration or unwanted movement of carriage assembly 60 are prevented. Rail assembly 62 further provides better access to carriage assembly 60 and better removeability of carriage assembly 60.

Blotter assembly 66 is shown in FIGS. 15-17. Blotter assembly 66 can be positioned at a peripheral location on printer housing 14, such that it is within the range of travel of carriage assembly 60 but off to the side of printing media 28. FIG. 16 shows print face 96 of carriage assembly 60 parked in front of blotter assembly 66, and FIG. 17 shows blotter assembly 66 wiping print face 96.

Blotter assembly 66 includes front housing 204 and removable rear housing 206. Rear housing 206 supports blotter paper supply roll 208. Blotter paper supply roll 208 is preferably a standard size of cash register tape which is widely available. While the blotting material is described as "paper" for ease of discussion, it will be recognized that blotter assembly 66 may use a material for blotting other than paper, and the type of blotting material is not significant to the invention. As indicated by arrows 210, blotter paper 212 is fed from supply

roll 208, over guide bars 214, 216, and in front of wipers 218, 220. Blotter paper 212 then returns around guide bar 222 and onto take-up spool 224. Take-up spool 224 and guide bars 214, 216, 222 are supported by front housing 204.

As shown in FIGS. 16 and 17, take-up spool 224 has slot 226 for receiving blotter paper 212. Slot 226 allows blotter paper 212 to be readily attached to take-up spool 224, similar to threading of film into a camera. This attachment is further secured by rotation of take-up spool 224 placing multiple winds of blotter paper 212 over take-up spool 224 and slot 226. Take-up spool 224 is rotated by motor 228 when desired to pull paper 212 from supply roll 208 and onto take-up spool 224.

The mechanism to press blotter paper 212 against print face 96 includes solenoid 230 and actuator arms 232. Solenoid plunger 234 is slideably received in plunger guide 236 on front housing 204. When rear housing 206 is positioned against front housing 204, solenoid plunger 234 is received within solenoid 230. Solenoid plunger 234 is pivotally attached to actuator arms 232 by attachment bar 238. Actuator arms 232 are pivotally attached to front housing 204 at pivot points 240. Wipers 218, 220 are supported between actuator arms 232. Wipers 218, 220 are preferably rotationally mounted on actuator arms 232, permitting rotational movement with blotter paper 212. Wipers 218, 220 can press blotter paper 212 against print face 96 without damaging print face 96 or jets 98.

As shown in FIG. 16, actuator arm 232 has a resting position wherein wipers 218, 220 are positioned off print face 96 and blotter paper 212 does not extend beyond front housing 204. Paper tension provided on take-up spool 224 normally holds actuator arm 232 in this resting position. Alternatively, actuator arm 232 may include a spring, be biased by solenoid 230, or otherwise be normally biased into this resting position. Blotter assembly 66 normally takes on this resting orientation throughout printing of printer 10, until wiping of print face 96 is desired. Wiping may be done initially at start up of printer 10, again after a specified number of copies or amount of ink usage,

and/or at any intervals as determined by user or software control.

When wiping of print face 96 by blotter assembly 66 is desired, carriage assembly 60 is positioned adjacent blotter assembly 66. Blotter assembly 66 then wipes print face 96 as shown in FIG. 17. Solenoid 230 is activated to pull solenoid plunger 234 rearward. This in turn pivots actuator arms 232 about pivot point 240, pressing wipers 218, 220 against print face 96. Wiper 218 is pressed against line of jets 94 to clean any ink gathered about line of jets 94. Wiper 218 is pressed against the lower edge of print face 96, where ink may gather due to gravity. With blotter paper 212 held in this position, motor 228 rotates take-up spool 224 to wipe blotter paper 212 across print face 96.

As shown in FIG. 15, take-up spool 224 includes spur gear 242. Front housing 204 and take-up spool 224 position spur gear 242 for connection to motor 228. This connection allows rotational force to be transmitted from motor 228 to take-up spool 224 even though take-up spool 224 is supported on front housing 204. As shown in FIGS. 16 and 17, front housing includes openings 246 for receiving take-up spool 224. Although only one opening 246 is shown, the other side of front housing (broken away in FIG. 15) may include a similar opening, to receive take-up spool 224 between spur gear 242 and side guide 244. Openings 246 allow take-up spool 224 to be rotationally carried by front housing 204 and further be readily removed from front housing 204. When paper supply roll 208 is fully used by blotter assembly 66, all of the paper from supply roll 208 will have been transferred to take-up spool 224. When paper supply roll 208 is replaced, take-up spool 224 is removed from front housing 204 and used paper 212 is removed from take-up spool 224. The separability between motor 228 and spur gear 242 allows take-up spool 224 to be removed without interference from motor 228.

Take-up spool 224 also includes side guides 244. Side guides 244 accurately position the paper across spool 224. As shown in FIG. 15, side guide 244 includes an opening 245 for placement onto take-up spool 224. Opening

245 in side guide 244 is slightly larger than spur gear 242, and thus side guide 244 can be removed from take-up spool 224 over spur gear 242. This allows used paper 212 to be removed off the side of take-up spool 224. Workers skilled in the art will appreciate that a removable side guide 242 could be used on either side or both sides of take-up spool 224. Removable side guide 242 allows used blotter paper 212 to be easily removed off the side of take-up spool 224 during replacement of blotter paper 212.

Blotter paper supply roll 208 is gravitationally retained in trough 248. Trough 248 allows paper supply roll 208 to be positioned and retained in rear housing 206 without a paper supply spool. Paper supply roll 208 is freely rotated when paper 212 is pulled off, subject only to friction associated with trough 248. Alternatively, tangs (not shown) may be provided on the sides of rear housing 206 to help in holding paper supply roll 208 in place and provide friction against rotation of supply roll 208. Because no paper supply spool is needed, insertion of paper supply roll 208 into rear housing 206 requires no steps other than setting paper supply roll 208 into trough 248.

Separability between front housing 204 and rear housing 206 allows ready access to paper supply roll 208 and/or paper take-up spool 226. This ready access is beneficial both for changing paper rolls and for maintenance of the blotter assembly 66. This separability benefit can be obtained by attaching either front housing 204 or rear housing 206 to printer housing 14, with the other housing portion removable therefrom. Separability between front housing 204 and rear housing 206 further allows ready removeability of take-up spool 226 during separation, but secures take-up spool 226 in opening 246 when front housing 204 and rear housing 206 are placed together.

FIG. 18 depicts a greatly enlarged view of a portion of an encoder strip 106. FIGS. 19 and 20 graphically represent a set of pulses produced by carriage 88 moving across encoder strip 106 from left to right. FIGS. 21-23 similarly show an encoder strip 106 and set of pulses produced, but in FIGS. 21-23 carriage 88 is moving from right to left.

Encoder strip 106 has a number of markings 250 which are relatively evenly spaced across the length of encoder strip 106. Markings 250 on encoder strip 106 may be shaded lines, holes or other markings which can be read and translated into a signal. Markings 250 may be photographically etched onto encoder strip 106, may be printed or etched by a laser, or may be placed onto encoder strip 106 by other means. With reference to print head 84 and carriage 88 shown in FIG. 3, markings 250 can be optically read by encoder strip reader 104 on carriage 88. While only a small portion of encoder strip 106 bearing markings 250f-n is shown in FIGS. 18-23, encoder strip 106 and markings 250 continue across the entire length of travel of carriage 88.

Each of markings 250 has a left edge 252, a right edge 254, and a width 256 therebetween. Each pair of adjacent markings 250 define a spacing 258 between markings 250. Adjacent left edges 252 have a distance 260 between them, and adjacent right edges 254 have a distance 262 between them. In a preferred embodiment for desired print resolution of 300 dots per inch, width 256 and spacing 258 are approximately 1/300th of an inch, and distances 260, 262 are approximately 1/150th of an inch. In this way, each marking 250 and each spacing 258 corresponds to a potential ink dot location or pixel.

Ideally, each width 256 and each spacing 258 would be uniformly equal. However, encoder strip 106 and markings 250 thereon may have a number of inaccuracies. Width 256 may not be uniform among all the markings 250 on encoder strip 106. This inaccuracy may occur particularly in a photographically etched encoder strip, as the photographic lens used in producing the encoder strip creates imaging errors which affect width 256. Photographically etched imaging errors tend to be greater toward the ends of an encoder strip 106 than they are in the middle of an encoder strip 106. Accordingly, markings 250 in the center of an encoder strip 106 may have a different width 256 than markings near an end of an encoder strip 106. Errors in width 256 may further occur due to inaccurate or non-uniform tensioning, due to thermal shrinkage or expansion of the encoder strip, due to other aberrations

in production, etc.

In addition to various uniformity errors in width 256, width 256 may not be equal to spacing 258 between markings 250. As shown in FIGS. 18 and 21, each marking 250 may have a width 256 which is slightly smaller than spacing 258. With a photographically etched encoder strip 106, distances 260 and distances 262 are generally more uniform across the length of encoder strip 106 than either widths 256 or spacings 258. There may be further errors in encoder strip 106 such that distances 260 or distances 262 are not uniform along encoder strip 106. All of these encoder strip errors can lead to inaccuracies in dot placement on a printed image.

Encoder strip reader 104 has two optical sensors, the location of which is represented by arrows 264 and 266. Optical sensors 264, 266 have a distance 268 between them. As will be explain below, distance 268 preferably positions optical sensors 264, 266 such that optical sensor 264 is in the center of a marking 250 when optical sensor 266 is at an edge 252, 254, and vice versa. When carriage 88 is traveling left to right as represented by the set of pulses in FIGS. 19 and 20, left edges 252 are leading edges and right edges 254 are trailing edges. When carriage 88 is traveling right to left as represented by the set of pulses in FIGS. 22 and 23, right edges 254 are leading edges and left edges 152 are trailing edges.

Optical sensor 264 produces a pulse A, and optical sensor 266 produces pulse B. Both pulse A and pulse B are binary signals, with changes between high and low values corresponding with edges 252 and 254 as each optical sensor 266 passes over markings 250. Each marking 250 produces high value 270 when read by optical sensors 264, 266, and spacing 258 between markings 250 produces low value 272 when optical sensors 264, 266 pass over it.

FIG. 19 shows the Pulse A and Pulse B signals read from the encoder strip 106, as a function of x-location on encoder strip 106. High values 270 are designated f-n corresponding to the encoder strip marking 250f-n which

produced the high value 270. As shown in FIG. 18-20, sensor 264 is presently located over marking 250n as carriage 88 moves from left to right across encoder strip 106. Sensor 266 is presently located between markings 250j and 250k.

FIG. 20 shows the pulses A and B as a function of time rather than a function of x-location. Each of high values 270 is again labeled according to the encoder strip marking 250 which created the high value 270. Because both encoder strip sensors 264, 266 are travelling at the same velocity at any given time, the durations of each high value 270 are similar at any point in time. However, the durations of high values 270 may change as carriage 88 accelerates and decelerates during a print scan. FIG. 20 illustrates carriage acceleration across markings 250f-i, prior to reaching relatively constant velocity across markings 250j-n.

Each high value 270 has a rising edge 274 and a falling edge 276. Distance 268 is not equal to a whole number of encoder strip markings 250, and thus high values 270 between pulse A and pulse B occur at different points in time. Accordingly, the timing of rising and falling edges 274, 276 from pulse B is different than the timing of rising and falling edges 274, 276 from pulse A.

The direction of carriage 88 can be determined from a comparison of the "leading falling edges" of pulse A and pulse B. When carriage 88 is traveling from left to right as represented in FIG. 20, each falling edge 276 of pulse A occurs when pulse B is at a high value 270. In contrast, each falling edge 276 of pulse B occurs when pulse A is at a low value 272. Pulse A therefore has a "leading falling edge" when carriage 88 is traveling from left to right.

FIGS. 22 and 23 represent pulses A and B when carriage 88 is travelling from right to left, or in the negative x-direction. The distance 268 between optical sensor 264 and optical sensor 266 remains constant regardless of direction of travel, but now optical sensor 266 is in front. As can be seen in FIG. 23 when pulses A and B are mapped as a function of time, each falling edge 276 of pulse A occurs when pulse B is at a low value 272, and each falling

edge 276 of pulse B occurs when pulse A is at a high value 270. Pulse B therefore has a "leading falling edge" when carriage 88 is traveling from right to left.

It should be understood that FIGS. 19, 20, 22 and 23 are simplified for description purposes, and may not accurately reflect signals actually received in a particular configuration. For instance, pulses A and B are shown as square signals with little or no noise. The actual signal may include significant noise and require filtering to arrive at a square signal. Resolution of pulse A can be increased by interpolating the timing of pulse A against a timer. Pulse A might thus be generated such that it changes from high to low or vice versa at two, three or four times the rate of leading edges on encoder strip 106. In any event, workers skilled in the art will recognize that various methods of creating pulses A and B from the encoder strip reader 104 may be employed. Workers skilled in the art will recognize that methods other than encoder strip 106 and reader 104 exist by which to produce a signal indicative of carriage location. The present invention is applicable to adjust any such signal indicative of carriage location with respect to a parameter of the printer.

To aid in simplicity of calculation, it is preferred that carriage 88 be driven such that print head 84 has a uniform velocity across the entire image. With a multiple print head system, it is preferred that the uniform velocity be maintained at all times that any print head 84, 86 is over the image. In the preferred embodiment printer 10 with image sizes up to 54 inches with two print heads 84, 86 and an offset of approximately six inches between the first and last jets 98 of the two print heads 84, 86, the desired velocity profile has 66 inch-wide section of constant velocity when either print head 84, 86 is above the image. The total travel of carriage 88 during printing includes approximately another six inches beyond each side of the image for carriage 88 to decelerate, reverse direction, and accelerate again to the desired constant velocity. The portion of the encoder strip 106 shown in FIG. 18 is the location where carriage 88 reaches uniform velocity when travelling from left to right. Accordingly, the

duration of pulses A and B gradually decreases during carriage acceleration until sensor 264 reaches marking 250k, at which point carriage 88 has reached uniform velocity. Because each sensor 264, 266 travels at the velocity of carriage 88, pulse A has the leading falling edge for left to right travel regardless of the increasing velocity of carriage 88.

FIG. 25 is a flow chart indicating the mechanism for print head firing in accordance with the present invention. Printer 10 conceptually includes a positional calculation circuit 280, a head control circuit 282, a drive motor control circuit 284, and a fire pulse adjuster circuit 286, all of which are interrelated. Each of these circuits 280, 282, 284, 286 may occur in a microprocessor, may occur in hardware, or may be otherwise implemented into the circuitry for printer 10 as desired.

Positional calculation circuit 280 includes encoder strip reader 104 which generates pulse A 288 and pulse B 290 as described above. Pulse A 288 and pulse B 290 are fed to a directional reference register 292. Directional reference register 292 compares leading falling edges of pulse A 288 and pulse B 290 to maintain a register signal 294 indicative of carriage 88 direction.

Positional reference register 296 is a counter indicative of the x-location of carriage 88. Positional reference register 296 counts up with each high value 270 received in pulse A when directional reference register 292 indicates travel in the positive x-direction, and counts down with each high value 270 received in pulse A when directional reference register 292 indicates travel in the negative x-direction. Positional reference register 296 produces a signal 298 which indicates the position of the carriage 88 on the printer 10. In a single print head system, this position 298 of the carriage 88 may be taken as corresponding directly to the position of the print head1 84. In a multiple print head system, the position of the carriage 88 may be taken as corresponding directly to the position of print head1 84, with remaining print head positions calculated therefrom.

Head2 position adjuster 300 calculates the position of the second

print head 86. Horizontal position adjust 302 and vertical position adjust 304 are added to the head1 position 298 to determine a head2 position 306. Horizontal position adjust 302 and vertical position adjust 304 may be determined based on nominal offsets between print head1 84 and print head2 86. Head2 86 may have a horizontal and vertical offset from head1 84 which differs from printer to printer based on manufacturing errors, and horizontal position adjust 302 and vertical position adjust 304 may alternatively be based on offsets between print head1 84 and print head2 86 which are measured during manufacture of printer 10. Horizontal position adjust 302 and vertical position adjust 304 may be further based on calibration results discussed earlier. Preferably all three sources of information are used to determine the adjustment to head1 position 298 to arrive at the correct head2 position 306.

The determination of which ink jets 98 on the print heads 84, 86 are to be fired for each fire pulse is performed by head control circuit 282. Source image data 310 is placed into an image data buffer 312, which may be a two-dimensional look-up table. Based on head1 position 298, head1 control 312 computes the x- and y-address of each ink jet 98 on head1 84. Head1 control 312 then references image data buffer 312 and determines a printing word 314 to be subsequently printed by the head1 84. Printing word 314 is a binary command with one bit for each ink jet 98, instructing each ink jet 98 to fire or not to fire on a given fire pulse. This printing word 314 is used with and-gate 316, such that the desired jets 98 of head1 84 print based on timing of adjusted pulse1 318. For a printer 10 with two print heads 84, 86, head2 control 320 operates similarly to head1 control 312, but using head2 position 306.

The overall velocity of an ink dot is a function of the firing velocity from the ink jet 98 and also the velocity of carriage 88. Ink dots have a z-direction velocity imparted by ink jet 98, and also have an x-direction velocity equal to the x-direction velocity of carriage 88. This x-direction velocity causes an ink dot to contact the media 28 at a significantly different x-location than the x-location of the ink jet 98 at firing. Particularly as the

velocity of carriage 88 increases to achieve faster print rates, this x-direction velocity cannot be ignored in accurate positioning of ink dots on the media 28. Accordingly, head1 control 312 and head2 control 312 also reference carriage direction 294 in retrieving the desired printing word 314.

The drive motor control circuit 284 preferably uses a proportional-integral-derivative loop ("PID loop") 322 to control the position and velocity of carriage 88. PID loops 322 are known to workers skilled in the art to control carriage drive motors 64, and generally work as follows. PID loop 322 times changes in the head1 positional signal 298 with timer 324, and compares these changes against a desired velocity profile 326. In this comparison, PID loop 322 looks at a proportional difference (i.e., the amount that carriage position differs from desired position), an integrated term (i.e., the sum of all the past errors in position), and a derivative term (i.e., the rate at which the proportional difference is changing). PID loop 322 controls the voltage applied to carriage drive motor 64 to see that position, velocity and acceleration of carriage 88 are all maintained as closely as possible to the desired velocity profile 326.

In contrast to prior art devices, neither pulse A 288 nor pulse B 290 is used to directly signal the timing of the firing of print heads 84, 86. Rather, pulse A is manipulated in fire pulse adjuster circuit 286 to provide adjusted fire pulses 318, 328 to both print head1 84 and print head2 86. Fire pulse adjuster circuit 286 adjusts pulse A 288 based on a parameter of the printer 10. Several different parameters may be used to adjust pulse A 288 to a desired signal for firing print head1 and head2 84, 86. In the preferred embodiment, a number of separate adjustments are made to pulse A 288 when used in firing.

A first adjustment to pulse A 288 is due to encoder strip inaccuracy discussed previously. Each marking 250 on encoder strip 106 is closely measured during manufacture of the printer 10 to determine any positional error associated with the marking 250. These positional errors are recorded as an encoder strip inaccuracy adjustment 330. Encoder strip inaccuracy adjustment 330 may be stored in a one-dimensional look-up table for

look-up based on the x-position of carriage 88.

Common pulse adjuster 332 references the encoder strip inaccuracy adjustment 330 based on the particular position of head 1, and adjusts the timing of pulse A 288 to account for any inaccuracy of encoder strip 106. In printers 10 with multiple print heads 84, 86, pulse A 288 is indicative of the overall x-position of carriage 88. If all print heads 84, 86 are carried on a single carriage 88, a single adjustment may be made to the timing of pulse A 288 based on the encoder strip inaccuracy 330, and the single adjustment applies equally to all print heads 84, 86.

The x-direction velocity of carriage 88 introduces a second error which is addressed by velocity adjustment 334 of fire pulse adjuster circuit 286. Due to various errors, carriage 88 does not exactly follow desired velocity profile 326, but rather is subject to small, instantaneous accelerations and decelerations. Sticking points or tight spots on rail 32, imperfect bearings for rollers 90, errors in the belt drive system of carriage drive motor 64 and other similar causes contribute to an instantaneous small velocity error. Accordingly, it is preferred that the actual instantaneous velocity of carriage 88 be used in making the velocity adjustment 334. Because PID loop 322 already calculates velocity of carriage 88, PID loop 322 can also supply instantaneous velocity data 335 to velocity adjustment 334.

Additionally, the velocity adjustment circuit 334 may store data from velocity calculations of previous runs across the image. Any sticking points or tight spots on the rail assembly 62 may cause recurring small velocity errors in carriage 88 travel. These recurring velocity errors can be predicted and accounted for in velocity adjustment 334. Ideally, velocity adjustment 334 will alter the timing of pulse A 288 taking into account both the instantaneous velocity 335 of the carriage 88 and historical data from previous velocity profiles of the carriage 88.

A third error occurs with regard to bi-directional printing. As discussed above, a delay time which occurs between sensing an encoder strip

marking and placing an ink dot on the media. This delay time is largely due to the flight time of the ink dot, but may further be due to electro-mechanical firing delay of the ink jet. In bi-directional printing, the delay time affects placement of the ink dot in different directions based on the direction of print head travel. Accordingly, common pulse adjuster 332 and velocity adjustment 334 take into account the direction of carriage travel 294.

A fourth error that can be addressed in a pulse adjustment circuit is "platen non-linearity offset" 336. Platen non-linearity offset 336 can be defined as any variation in the distance between ink jets 98 and the surface of platen 42. In a perfect mechanical system, the distance from heads 84, 86 to platen 42 would be maintained at a constant value, and the position of printed ink dots on the media 28 would be highly predictable. However, printers are not mechanically perfect. Platen 42 may have warpage, curvature, improper alignment or other manufacturing and assembly tolerance errors. The carriage assembly 60 and the rail assembly 62 could also have such alignment problems. These problems affect printing quality as follows. As explained above, ink droplets fired from moving print heads 84, 86 have an x-direction velocity which cannot be ignored. The location that an ink droplet contacts the media 28 (x) is dependant upon the firing location (x_{firing}), upon the x-direction velocity of the ink droplet (v_x), and upon the travel time of the ink droplet (t): $x = x_{firing} + (v_x \times t)$. The travel time of the ink droplet is dependant upon the y-direction firing velocity of the ink droplet (v_y), upon the distance between the ink jet 98 and platen 42 (d_{platen}), and upon the media thickness (t_{media}): $t = v_y(d_{platen} - t_{media})$. Accordingly, if the distance between the ink jet 98 and the platen 42 varies from location to location, this difference can cause positioning errors in the placement of ink droplets.

In the preferred embodiment, platen non-linearity offset 336 is addressed in fire pulse adjuster circuit 286. The amount of any variation in distance between platen 42 and carriage 88 is measured during manufacturing of printer 10 and recorded as platen non-linearity offset 336. Platen non-linearity

offset 336 may be stored in one-dimensional look-up table for look-up based on the x-position of carriage 88. Based on the head1 position signal 298, pulse1 adjuster 338 references platen non-linearity offset 336 and adjusts adjusted pulse 340 for any error, thereby forming adjusted pulse1 318. Adjusted pulse1 318 is used to time the firing of head1 84.

On a multi-head printer, the error from platen non-linearity offset 336 may be separately handled for each print head 84, 86. Pulse2 adjuster 342 references platen non-linearity offset 336 similar to pulse1 adjuster 338, but using the head2 position signal 306. Pulse2 adjuster 342 adjusts adjusted pulse 340 to get adjusted pulse2 328. Adjusted pulse2 328 is used to time the firing of head2 86. The pulse2 adjuster 342 may further account for the horizontal position adjustment 302 to time the firing of head2 86 to an accuracy greater than the nearest horizontal pixel.

Workers skilled in the art will appreciate that these various techniques can be modified or improved based upon the particular situation. For instance, fire pulse adjuster circuit 286 may take the thickness of media 28 into account in adjusting the timing of pulse A 288, particularly for bi-directional printing.

For print heads wherein printing occurs at multiple y-locations as well as multiple x-locations, the platen 88 may have warpage or misalignment in the y-direction as warpage in the x-direction. "Platen planarity offset", i.e., the amount the each x-y location on platen differs from a planar surface defined by print head 84, could be measured and recorded. The pulse adjuster circuit could then adjust the firing pulse such that each ink jet is fired independently based on its particular distance between the jet and the media. Similar adjustments could be made for multiple print heads offset in the y-direction.

In the preferred embodiment, both encoder strip inaccuracy 330 and platen non-linearity offset 336 are measured during manufacture of printer 10. While measure during manufacture will largely correct these errors, part of the errors may be due to environmental parameters such as printer temperature,

humidity, etc. These or other errors of printer 10 may be more accurately corrected by installing a sensor to calculate the parameter during printing.

The present invention contemplates adjusting pulse A 288 by other parameters of printer 10. For instance, parameters such as ambient temperature, printer temperature, humidity, ink viscosity (which may differ based not only on different or non-homogenous types of ink but also based on differing ink temperature at various x-locations or y-locations on the image), or any other parameter that may affect the final output can further be accounted for in the fire pulse adjuster circuit 286 to appropriately determine the timing used for firing of the print heads 84, 86.

By adjusting pulse A 288 based on these parameters of the printer 10, ink dots may be printed in precise controlled locations on the image. This precise locational control helps to avoid problems such as banding, stitching, and granularity.

II. PAPER HANDLING SYSTEM

As best seen in FIGS. 2 and 25, paper handling system 22 begins with supply spool 30 for holding paper supply roll 32. Paper 28 travels from supply spool 30 past a plurality of drive rollers 36 and a corresponding plurality of pinch rollers 38. The drive rollers 36 are rotated by a drive motor 500. The drive motor 500 is preferably a servo-motor with an integral rotary optical encoder for position-feedback sensing. The rotary optical encoder preferably provides a resolution of 200 positions per revolution of the servo motor armature and provides quadrature read-out of the rotary encoder disk, which increases position feedback resolution to 2000 positions per revolution (500 ppr x 4 = 2000 ppr). Thus, the servo-motor provides accurate mechanical positioning of paper 28 in much the same way as a "stepper" motor. That is, the servo-motor produces a known angular rotation by "stepping" from one angular position to another a known number of positional advances as determined from the integral rotary optical encoder. By "stepping" drive motor 500 a predetermined number of "steps" using a servo-motor, paper 28 can be accurately advanced a known

distance. The higher-speed servo-motor advances paper 28 at a much faster rate than traditional "stepper" motors can achieve.

Paper 28 continues past print heads 84 to tensioning spool 510. Tensioning spool 510 is an intermediate take-up spool which is controlled by tensioning apparatus 512. Tensioning spool 510 and tensioning apparatus 512 provide a uniform web tension across the entire width of paper 28 as paper 28 is wound about tensioning spool 510.

As best seen in FIG. 25, after an image is printed on paper 28 and the portion of paper 28 containing the printed image is wound onto intermediate tensioning spool 510, paper 28 is cut. Paper 28 is then attached to take-up spool 514 such that paper 28 contacts heater 516 and quencher 518 as paper 28 travels from tensioning spool 510 to take-up spool 514. Take-up drive motor 515 rotates take-up spool 514. Tensioning fingers 519 extend from quencher 518 and exert light pressure on paper 28 to ensure no slack exists in paper 28 such that paper 28 stays in continuous and even contact with heater 516 and quencher 518.

The separate processes of printing the image on paper 28 and heating the printed image are performed in a serial manner to optimize the image throughput speed of paper 28 in each process. The components of paper handling system 22 are arranged such that the image printed on paper 28 is not touched during the separate printing and heating processes. In particular, drive rollers 36 and pinch rollers 38 are located such that paper 28 is "pushed" past print heads 84 rather than "pulled" past the print heads. By placing drive rollers 36 and pinch rollers 38 in an "upstream" location from print heads 84, no drive wheels or rollers need contact the printed image after it has been created on paper 28. Similarly, the orientation of heater 516 and quencher 518 is such that the side of paper 28 containing the printed image does not contact the surfaces of heater 516 or quencher 518 which could damage the printed image. Minimizing contact with the printed image before the image has been heated is especially important when using hot melt ink, as the ink may be scraped off or flake off the paper 28 prior to heating by scuffing or rubbing.

When printing high quality color images, it is important that a printing system be able to accurately and consistently produce an image and reproduce the colors contained in the image. However, as previously noted, there are many different types of printing mediums which may be used. Different printing mediums have different handling characteristics (media thickness, stiffness, feed rates, coatings, calorimetric effects on color reproduction, etc.) and will react to exposure to heat, different types of ink, and tensioning forces quite differently. The differences between printing mediums can lead to problems such as cockling of the media, or banding effects in the printed image. Therefore, to accurately and consistently produce a printed image, it is important that several parameters be known and monitored during the printing process. These parameters include the printing medium characteristics such as the media type (e.g., coated matte paper, coated glossy paper, translucent film, clear film, vinyl, canvass, etc.), media dimensions, and the amount of the printing medium available to be printed on. The particular printing medium characteristics are used in the control of the media speed and tension, the heating and cooling profiles of the media, and many other printer operations which may be affected by the media characteristics.

To ensure consistent and accurate results, it is desirable to eliminate as many sources of potential error as possible from the printing process. One potential error source is user error, which occurs when a user adjusts the printing system to accommodate different printing mediums. It is therefore preferable to eliminate the requirement that a user set controls or choose input data regarding operation of the printer for a given printing medium when printing an image. To accomplish this, it is important that the printer be able to determine the characteristics of the printing medium and ink which is being used and to automatically adjust itself accordingly to achieve the desired results. For example, to accurately reproduce a particular color on two different printing mediums, it may be necessary for the printer to adjust the manner in which the ink is placed on the two printing mediums. A slight variation in the

amount or combination of inks which are used may be necessary, the feed rate of the medium through the printer may require adjustment, the tension on the medium may need to be modified, or the heating and cooling profile of the printed image may need to be altered. It is preferred that the printer be capable of making such adjustments without requiring any input from the user and thus eliminate user error as one potential source of error.

The ink jet printer 10 of the present invention addresses the need to recognize and monitor the printing medium and the ink, and to automatically adjust the operation of the printer in response to the type of printing medium and ink being used. A memory unit called a media profiler 530 (schematically shown in FIG. 26) contains information which is desired or necessary for adjusting operation of printer 10. Media profiler 530 may comprise any device capable of providing information indicative of characteristics of the printing medium, such that one printing medium may be identified and distinguished from a plurality of media. For example, media profiler 530 may comprise a switch array, fuse logic, a read only memory (ROM) chip, or a readable and writable memory chip. The media profiler 530 preferably accompanies each new supply of paper 28 and is preferably disposable when the printing medium supply is exhausted. When a new supply of paper 28 is mounted on supply spool 30, the accompanying media profiler 530 is coupled to controller 532 by an interfacing link. Media profiler 530 thus may communicate with controller 532 in printer 10, such that the information stored in media profiler 530 may be retrieved, used and modified by controller 532.

As seen schematically in FIG. 26, controller 532 is in electrical communication with all systems of printer 10, including ink supply system 24, print head system 26, media advance motor 500, tensioning apparatus 512, heater 516, quencher 518, and take-up motor 515. While media profiler 530 is described herein as a separate unit which accompanies the printing medium, those skilled in the art will recognize that media profiler 530 may alternatively be formed as an integral part of the media supply. For example, media profiler

530 may be integrally formed as part of the media supply spool 30.

The information stored by media profiler 530 is preferably indicative of characteristics of paper 28 such as, for example, the type of paper 28 (e.g., matte coated, glossy coated, etc.), the dimensions of the printing medium (e.g., thickness, width, length), and any other information necessary for controller 532 to properly identify the media and operate the printer. The data contained in media profiler 530 is used by printer controller 532 for multiple purposes, including creating the proper tension in paper 28, determining the proper advancement of the paper 28 through the printer, and controlling the heating and cooling of the image to accurately reproduce colors in the printed image.

As noted above, media profiler 530 may comprise any of a variety of devices capable of storing information identifying and distinguishing one printing medium from a plurality of printing media. In some instances, media profiler 530 may have a storage capacity large enough to store the actual characteristics of a printing medium which are necessary for operation of printer 10. In most instances, however, the storage capacity of media profiler 530 will not be large enough to store the actual characteristics of the printing medium. For this reason, it is preferred that media profiler 530 provides information indicative of characteristics associated with the printing medium.

In a preferred embodiment, controller 532 includes a look-up table containing the parameters of operation for printer 10 for each of a plurality of printing media. For a particular printing medium, the look-up table contains parameters, for example, such as printing medium advancement speed, printing medium tension, and printing medium heating profile which are dependent on characteristics associated with the printing medium. Media profiler 530 indicates to controller 532 which particular printing medium is being supplied to printer 10, and controller 532 then uses information in the look-up table associated with the particular printing medium to operate printer 10. In this manner, media profiler 530 may be made of less expensive devices, thereby reducing the cost

of printer 10.

In a preferred embodiment, media profiler 530 is readable and writable memory unit such that controller 532 may modify some information in media profiler 530. For example, media profiler 532 preferably provides information indicating the length of printing medium available for use. Preferably, controller 532 is capable of modifying the information in media profiler 532 to reflect changes in the length of printing medium available for use as the printing medium is used, such that controller 532 ma alert the user if an inadequate amount of printing medium is available for a particular print job.

As noted earlier, advancement of paper 28 by drive rollers 36 is dependent upon accurate regulation of the tension in paper 28 as it travels past print heads 84. Specifically, changes in the differential tension across the nip point of drive rollers 36 and pinch rollers 38 should be minimized as paper 28 is advançéd by drive rollers 36. Tensioning spool 510 and tensioning apparatus 512 provide means for accurately maintaining tension in paper 28, thus minimizing variations in the differential tension across the nip.

Tensioning spool 510 preferably includes a mechanism for securing paper 28 along the length of tensioning spool 510. For example, as seen in FIG. 26, a slot 536 may be provided along the length of tensioning spool 510. The edge of paper 28 is inserted into slot 536 and tensioning spool 510 rotated about its longitudinal axis. As tensioning spool 510 rotates about its axis, paper 28 is secured to tensioning spool 510 along the entire length of tensioning spool 510 by wrap friction. Any other method known in the art for securing paper 28 to tensioning spool 510 would function equally well. For example, paper 28 could be secured to tensioning spool 510 by the use of tape or other adhesive, or mechanical fastening means such as grippers or clamps.

Tensioning apparatus 512, best seen in FIG. 26, uses spring 540 to exert a force on drive shaft 542 which in turn creates tension in paper 28. Spring 540 is preferably a torsion spring wrapped about drive shaft 542. Drive shaft 542 communicates with tensioning spool 510 via timing gears 544 and 546

and timing belt 545 such that when drive shaft 542 rotates, tensioning spool 510 also rotates. Indexing disk 550 is attached to drive shaft 542 and is used to monitor the rotation of drive shaft 542. Indexing disk 550 contains a plurality of index marks 552 which are detected by sensor 554. Indexing disk 550 rotates with drive shaft 542, and by determining the number of index marks 552 passing sensor 554, the rotation of drive shaft 542 and tensioning spool 510 can be monitored and constant tension maintained on tensioning spool 550.

As seen in FIG. 26 and described above, spring 540 is wrapped about drive shaft 542 such that spring 540 exerts a rotational force against drive shaft 542. First end 556 of spring 540 is fixed to shaft 542 by any means known in the art. For example, first end 556 of spring 540 may be attached to shaft 542 by welding, a clamping mechanism, an adhesive, or by forcing first end 556 of spring 540 against a surface extending from the circumference of shaft 542. As shown in FIG. 26, first end 556 of spring 540 is attached to disk 547 which in turn is solidly fixed to shaft 542. Second end 558 of spring 540 is fixed to pulley 560. Drive shaft 542 extends through the center of pulley 560, and pulley 560 rotates independently of drive shaft 542 by means of ball bearing 559. Pulley 560 is connected to tensioning motor 570 via drive belt 572. By rotating pulley 560 with tensioning motor 570, spring 540 may be wound and the potential energy stored in spring 540 may be adjusted to a desired level. The potential energy stored in spring 540 is a function of the spring constant and the distance over which force is applied. Therefore, by rotating pulley 560 (and thus winding spring 540) a known amount, a known potential energy may be stored in spring 540 and a known force will be exerted by spring 540 on drive shaft 542.

To facilitate rotating pulley 560 a known amount and thereby winding spring 540 through a known number of revolutions, tensioning motor 570 is preferably a "stepper" motor which produces angular rotation by "stepping" from one angular position to another. Preferably, one "step" of tensioning motor 570 equals one index mark 552 on indexing disk 550 such that

the angular rotation of pulley 560 caused by one "step" of tensioning motor 570 equals the angular rotation of shaft 542 which results when one index mark 552 passes sensor 554.

After winding spring 540 a known amount to achieve a desired force, tensioning motor 570 is shut off, and pulley 560 is held stationary relative to drive shaft 542. Spring 540 thus urges rotation of drive shaft 542 and tensioning spool 510. If paper 28 is not attached to tensioning spool 510, the potential energy of spring 540 will cause tensioning spool 510 to rotate freely, spring 540 will quickly unwind and the potential energy of spring 540 will be reduced to zero. However, if paper 28 is attached to tensioning spool 510, tensioning spool 510 will be unable to rotate freely since it is constrained by paper 28. The force generated by spring 540 will then produce a known web tension in paper 28 across the entire width of paper 28. The tension in paper 28 is a function of the force exerted by spring 540, the ratio of timing gears 544, 546 and timing belt 545, and the radius of paper 28 on tensioning spool 510. As paper 28 is advanced by drive rollers 36, spring 540 will cause tensioning spool 510 to slowly rotate and take up any slack produced in paper 28 by the paper advance. As paper 28 continues to be advanced and tensioning spool 510 continues to rotate, spring 540 will gradually unwind and the force exerted by spring 540 transmitted to tensioning spool 510 will decrease. Therefore, to maintain the tension in paper 28 at a near constant level, spring 540 must be periodically rewound.

After the initial tension in paper 28 is set by winding spring 540 with tensioning motor 570 as described above, controller 532 continues to monitor the rotation of drive shaft 542 via indexing disk 550 and sensor 554. As paper 28 is advanced by drive rollers 36, controller 532 monitors the rotation of drive shaft 542 via indexing disk 550 and calculates the radius of paper 28 on tensioning spool 510. The radius of paper 28 on tensioning spool 510 must be computed because as the radius increases, an increased force must be exerted by spring 540 to maintain a constant web tension in paper 28. As the required force

to maintain web tension increases, the amount which spring 540 must be wound around drive shaft 542 also increases. To maintain a constant tension in paper 28, the force exerted by spring 540 must increase proportionally to the radius of paper 28 on tensioning spool 510.

The radius of paper 28 on tensioning spool 510 may be calculated in the following manner: Paper 28 is advanced a predetermined distance by drive rollers 36. As paper 28 is wound onto tensioning spool 510, indexing disk 550 also rotates. The relationship between the rotation of indexing disk 550 and tensioning spool 510 is a function of the size of timing gears 544 and 546 and is a known value. Indexing disk 550 has a known number of index marks 552 about its circumference. By counting the number of index marks 552 which pass sensor 554 during each advancement of paper 28, the number of revolutions or fraction thereof for tensioning spool 510 may be calculated. For example, assume indexing disk 550 has 500 index marks 552 about its circumference and rotates four times for each revolution of tensioning spool 510. Further, assume paper 28 advances in 0.160 inch increments. Now, as paper 28 is advanced, controller 532 counts the number of indexing marks 552 which pass sensor 554. Assume 25 index marks 552 are counted by controller 532. Because four revolutions of indexing disk 550 are required for one revolution of tensioning spool 510, it is known that 2,000 index marks 552 (4 revolutions times 500 index marks/revolution) will pass sensor 554 during one complete revolution of tensioning spool 510. If one paper advancement results in 25 index marks 552 passing sensor 554, tensioning spool 510 must have completed 25/2,000ths of a revolution. Because the distance of paper advancement is known to be 0.160 inches, it is also known that 0.160 inches equals 25/2,000ths of the circumference of paper 28 on tensioning spool 510. The circumference of paper 28 on tensioning spool 510 must thus be 2,000/25 times 0.160 inches, or 12.8 inches. The radius of paper 28 on tensioning spool 510 is thus 12.8 inches/2π, or 2.04 inches.

In a preferred embodiment, media profiler 530 contains data

representing the length of paper 28 on paper supply roll 32. As controller 532 monitors the radius of paper 28 on tensioning spool 510, it also determines the length of paper 28 which has been removed from paper supply roll 32 and the amount of paper 28 remaining on paper supply roll 32. The information in media profiler 530 is then updated by controller 532 to indicate the length of paper 28 remaining on paper supply roll 32. The data in media profiler 530 may be updated continuously, at the completion of each print job, or at some periodic frequency therebetween. Printer 10 may then warn a user if inadequate lengths of paper 28 are available to complete a print job at any given image size or number of copies.

After the radius of paper 28 on tensioning spool 510 has been determined in the manner described above, the force which must be exerted by spring 540 to maintain a predetermined tension in paper 28 may be calculated. Tensioning motor 570 is then activated to wind spring 540 such that the desired force is generated by spring 540. The force exerted by spring 540 may be continuously adjusted, or alternatively the force may be periodically adjusted as spring 540 unwinds and the radius of paper 28 on tensioning spool 510 increases. If the tension in paper 28 need only be maintained within a predetermined range, then only periodic adjustment of the force exerted by spring 540 is necessary to keep the tension within the desired range.

In a preferred embodiment, the force exerted by spring 540 results in a force of approximately 2 pounds or less across the web of paper 28. As discussed above, changes in the differential tension of paper 28 across the nip point of drive rollers 36 and pinch rollers 38 should be minimized as paper 28 is advanced by drive rollers 36. By maintaining the force across the web of paper 28 at a low level, any variations in the force are correspondingly small, and the potential changes in the differential tension across the nip point are small. By thus minimizing the magnitude of possible changes in the differential tension, errors in advancement of paper 28 are minimized.

While tensioning apparatus 512 maintains the tension in paper 28

in a predetermined range as paper 28 advances past print head 84, the tension in paper 28 on the supply spool 30 side of drive wheels 36 preferably remains as close to zero tension as possible. While some prior art printers use friction brakes on the print medium supply roll to maintain nominal tension in the print medium immediately available from the supply roll, friction brakes or similar devices do not provide a constant web tension in the media. Rather, the web tension decreases as the radius of the supply roll decreases. Therefore, supply spool 30 and paper supply roll 32 are preferably supported in a manner which minimizes resistance to rotation. By maintaining the tension in paper 28 near zero on the supply side of the drive rollers 36 and by maintaining a low constant tension in paper 28 on the take-up side of drive rollers 36, any changes in the differential tension across the nip between drive rollers 36 and pinch rollers 38 remains nearly constant. By maintaining a constant differential tension across the nip, variations in the rate of advancement of paper 28 are minimized.

In a preferred embodiment, the use of tensioning apparatus 512 as described above, together with servo drive motor 500 and grit drive rollers 36, allows paper 28 to be advanced by drive rollers 36 to an accuracy of 0.0001 inches. Precise paper advance stepping to an accuracy of 0.0001 inches avoids having to multi-pass print to attain graphics quality images with the resultant slow-down in print speeds.

As best seen in FIG. 25, after the printed image has been created on paper 28 and has been wound onto tensioning spool 510, paper 28 is cut between drive rollers 36 and tensioning spool 510. Paper 28 may be cut by hand by the operator of the printer, or a cutting mechanism may be provided to cut paper 28 along its width. A cutting mechanism may be controlled by controller 532 to automatically cut paper 28 upon completion of a print job. The free end of paper 28 which contains the printed image is guided past heater 516 and quencher 518 and onto take-up spool 514. To reduce cockling of paper 28, heater 516 and quencher 518 are preferably provided with a curved profile, as best seen in FIGS. 2 and 25. The curved profile of heater 516 and quencher 518

tends to stiffen paper 28 against buckling and cockling as paper 28 passes around heater 516 and quencher 518. As the radius of curvature of heater 516 and quencher 518 decreases, the effectiveness in preventing cockling of paper 28 is increased. It is therefore preferable to provide heater 516 and quencher 518 with a radius of curvature which is as small as possible while still maintaining an adequate surface area to create the desired heating and cooling profiles of paper 28. In the preferred embodiment, heater 516 and quencher 518 have a radius of curvature of approximately 2 inches. As noted above, it has been discovered that for heating of images printed with a hot melt ink, the smaller the curvature or outside radius of the heater, the better the control of cockling effects. This is true up to a minimal curvature or outside radius of the heater unit, in the range below 2.0 inches, at which point drag forces make control of media tension much more difficult. Additionally, the ink can fracture or flake from the media due to the more acute wrap angle.

Take-up spool 514 is driven by motor 515 and spur gear drive (not shown) which pulls paper 28 containing the printed image over heater 516 and quencher 518 at a predetermined rate for the medium type. Heater 516 allows the ink previously deposited on paper 28 to melt slightly, liquify, and thereby spread across the medium surface and securely bond with paper 28. As the ink melts and spreads, the rough surface and "embossed" characteristics of the printed image are reduced. Quencher 518 quickly cools the ink to its solid state after the ink has spread a desired amount.

The temperature of heater 516 is set by controller 532 to achieve the desired amount of spreading of the ink and is dependent upon factors including the melting temperature of the ink and the type of paper 28 or other media used. The temperature of heater 516 is preferably generated by resistance heating, but may be generated by any other means known in the art. In addition, the heating of heater 516 is preferably "zoned" such that when a media of width less than the maximum allowable width is used, only that portion of heater 516 over which the narrower media passes is heated. Quencher 518 preferably is air-

cooled to create a heat sink capability suitable for cooling paper 28. Fans are used to direct air over quencher 518 to aid in removing heat from quencher 518. While quencher 518 is depicted as air-cooled, it may also be cooled by any other means known in the art, such as by liquid-cooling.

Minimization of temperature gradients across the width of the image is important to maintain a graphics-quality image. In very large format printers, uneven temperatures are more likely to occur from one side of the media to the other side of the media. Therefore, the material used to form heater 516 and quencher 518 preferably provides a high lateral thermal conductivity, thereby minimizing temperature gradients across the width of the heater 516 and quencher 518.

Heater 516 and quencher 518 cooperate to create a desired heating and cooling profile for paper 28 or other media used. Media profiler 530 preferably contains data representing the preferred heating and cooling profile for the paper 28 which is currently being used in the printer 10. Controller 532 selects the heating and cooling profile based upon information contained in media profiler 530. The information in media profiler 520 preferably determines the temperature of heater 516 and quencher 518, as well as the speed and tension of paper 28 over heater 516 and quencher 518. Optimum heating and cooling of the printed image on paper 28 or other media used may thus be obtained for different printing media.

As noted above, when using contact heating and quenching to remelt the ink image on the print medium, it is important to maintain constant and uniform contact between the media and the heating/quenching elements. Failure to maintain constant and even contact with heater 516 causes the ink to heat and spread non-uniformly on the print medium. Non-uniform spreading of the ink results in uneven color reproduction and visible banding across the image which is unacceptable for graphics-quality images. As the width of the media increases, it becomes more difficult to maintain even and uniform contact between the media and heater 516. For example, as media width increases, the

media tends to sag away from heater 516 and quencher 518 so paper 28 may contact heater 516 along the outer edges of paper 28, but not near the center of paper 28. Also, as media width increases it becomes more difficult to maintain an even tension across the media. That is, it is more difficult to ensure that the tension in the media is consistent from one side to the other such that one side of the media does not droop or sag because it is in lower tension. Such uneven tension across the width of the media could be caused, for example, by misaligned (non-parallel) spools 510 and 514. It is also more difficult to ensure the manufacturing accuracy (i.e., straightness) of take-up spools 510 and 514, and of heater 516 and quencher 518 themselves. The spools 510, 514 and the heater 516 or quencher 518 may be bowed, for example, and the media will not maintain uniform contact with heater 516 as a result.

To overcome the problems relating to non-uniform contact between paper 28 and heater 516, the present invention utilizes a means to maintain contact between paper 28 and heater 516. Preferably, the means to maintain contact comprises flexible members which removes slack from paper 28 and forces paper 28 into contact with heater 512. The use of a flexible member across the width of paper 28 allows slack to be taken up only where slack exists without significantly affecting the overall tension in paper 28. Preferably, there are a plurality of independent flexible members spaced across the width of paper 28. For example, in a preferred embodiment, flexible fingers 519 (FIG. 25) extend from quencher 518 and exert light pressure on paper 28 to take up any slack that may exist in paper 28 such that paper 28 stays in continuous contact with heater 516. The fingers 519 preferably extend across the width of heater 516, and are preferably adjustable such that the force exerted by the fingers 519 may be altered individually. In the preferred embodiment, the plurality of flexible fingers 519 are configured and arranged to minimize the possibility of marring the image on paper 29 or paper 28 itself. For example, fingers 519 are positioned to exert pressure on the back side of paper 28 opposite the image, and therefore avoid touching the image. Also, fingers are preferably

wide enough to prevent creasing of paper 28 due to an insufficiently wide pressure point formed by fingers 519.

Instead of flexible fingers 519 as shown in FIG. 25, the means to maintain contact between paper 28 and heater 516 may alternatively be comprised of independent idler rollers pressed against paper 28 by a spring or some other force. The means to maintain contact could also be a unitary strip or roller extending across the width of paper 28, the strip or roller exerting a light force on paper 28 such that slack in paper 28 is removed. For example, a string of sufficiently heavy "beads" could be strung across paper 28 such that the weight of the beads removes any slack from paper 28 and maintains contact between paper 28 and heater 516. The means for maintaining contact could also be positioned along the path of paper 28 prior to the point at which paper 28 contacts heater 512. For example, fingers 519 could extend from heater 516 to exert pressure on paper 28, as seen in FIGS. 2 and 3. Alternatively, the means for maintaining contact could be positioned both before and after heater 516. As those skilled in the art will recognize, the means for maintaining contact between paper 28 and heater 516 may also comprise many alternative embodiments other than those described above.

If heater 516 or quencher 518 are bowed, thereby causing slack in paper 28, it is possible to adjust the straightness of heater 516 and quencher 518 using the adjustment device depicted in FIG. 27. Bar 584 is mounted above heater 516. Bar 584 is spaced from heater 516, and bolt 585 extends through bar 584 into heater 516. Bolt 585 threadably engages heater 516 such that by turning bolt 585, the center of heater 516 may be drawn toward or moved away from bar 584, thereby altering the "bow" of heater 516. A similar device may be used to adjust quencher 518.

In addition to the desired effects of improving the image quality described above, heater 516 has the undesired effect of expelling moisture from paper 28. The loss of moisture content caused by heating paper 28 causes paper 28 to shrink in a non-uniform manner, i.e., to cockle. In addition to using a

curved heating surface as described above, cockling of paper 28 may be reduced by increasing tension in the paper 28 as the printed image is heated. Tension in paper 28 during heating tends to stretch the paper 28 and reduce the effects of any cockling which occurs.

Tensioning apparatus 512 is used to provide tension in paper 28 as the printed image on printing medium is heated. The operation of tensioning apparatus 512 as paper 28 is unwound from tensioning spool 510 is very similar to the operation of tensioning apparatus 512 described above. In particular, as paper 28 is unwound from tensioning spool 510, spring 540 exerts a force which tends to resist removal of paper 28 from the tensioning spool 510. As paper 28 is removed from tensioning spool 510, spring 540 is wound tighter about drive shaft 542 and the force exerted by spring 540 increases. To maintain the tension in paper 28 at a desired and predetermined constant level, controller 532 continuously monitors the rotation of drive shaft 542 and radius of paper 28 on tensioning spool 510 as described above. Periodically or continuously, in the same manner as described above, controller 532 will operate tensioning motor 570 to adjust the potential energy of spring 540 to maintain the desired tension in paper 28 during heating and cooling of the media. Instead of winding spring 540 tighter about drive shaft 542, as described above, when paper 28 is wound onto tensioning spool 510, the direction of tensioning motor 570 is reversed and spring 540 is unwound to decrease the force generated by spring 540 as the radius of paper 28 about tensioning spool 510 decreases.

In a preferred embodiment the tension in paper 28 during heating results in a force across the web in the range of 10 pounds. However, as noted earlier, tensioning apparatus 512 is preferably designed to provide a force in the range of 2 pounds or less across the web during printing. Therefore, one-way drag clutch 590 (FIG. 26) is used to provide an additional resistance force during heating of the printed image. As best seen in FIG 26, drag clutch 590 is attached to take-up spool 510 opposite tensioning apparatus 512. Drag clutch 590 does not affect tension in paper 28 as paper 28 is advanced by drive rollers

36, and functions only to provide additional tension in paper 28 as paper 28 is removed from take-up spool 510 and transported past heater 516 and quencher 518. Drag clutch 590 provides a constant force in paper 28, preferably in the range of 7 to 10 pounds in addition to the force provided by tensioning apparatus 512. Tensioning apparatus 512 then functions in the manner described above to maintain the force across the web at a desired magnitude.

III. INK SUPPLY SYSTEM

Figures 28-35 provide a more detailed illustration of various aspects of ink supply system 24 of the present invention. Figures 28 and 29 illustrate an ink reservoir and pump configuration of ink supply system 24 adapted for use with hot melt ink jet printers in accordance with preferred embodiments of the present invention. Figure 30 illustrates a profiler system which provides the ink supply system controller with information related to the chromatic characteristics and the quantities of ink introduced into the system. Figure 31 illustrates a circuit used to determine whether heatable tubes are properly connected for delivering ink to the ink jet head. Figure 32 is a block diagram illustrating a control system for controlling operation of the printer, and more particularly, for controlling operation of ink supply system 24. Figures 33-34 illustrate an ink supply system in accordance with alternate embodiments of the present invention which is particularly adapted for use with aqueous, semi-liquid or semi-solid inks. Figure 35 illustrates an ultra-violet (UV) light ink curing device for use with ink jet printers which employ an ink supply system as shown in Figures 32-24 and which require curing other than by cooling of the ink to solidify ink on the print medium.

As shown in Figure 28, ink supply system 24 includes four individual upper reservoirs 50A-50D, lower reservoir assembly 52 which includes four individual lower reservoirs 52A-52D, gear motor 1004, drive shaft 1007, cam links 1012A-1012D for driving pistons 1016A-1016D (piston 1016A is shown in Figure 26), pump 1020 for providing a vacuum source and a pressure source for ink de-aeration functions of ink jet heads 84 and 86, filters 1024A-

1024D for filtering ink pumped from lower reservoirs 52, supply tubes 1028A-1028D for providing fluid paths between the individual lower reservoirs and the ink jet heads upon demand, and drain tubes 1032A-1032D for providing fluid paths between the individual lower reservoirs and drain 1036 upon demand. Upper reservoirs 50A-50D (collectively referred to as upper reservoirs 50) are each adapted for receiving a supply of a separate and predetermined one of four colors of ink - cyan, yellow, magenta, and black. Upper reservoirs 50 are designed to receive the new supplies of the individual colors of ink and to maintain the new supplies of ink separate from ink in lower reservoirs 52A-52D (collectively referred to as lower reservoirs 52) in order to prevent overflow or contamination of ink in reservoirs 52.

In preferred embodiments, ink jet printer 10 is a hot melt ink jet printer and ink supply system 24 is adapted for supplying hot melt ink. However, in alternate embodiments, ink jet printer 10 is an ink jet printer adapted to print with other types of inks, such as aqueous inks, semi-liquid inks and semi-solid inks. In these alternate embodiments, ink supply system 24 is adapted for supplying one or more of these other types of inks. An example of these alternate embodiments is discussed below with reference to Figures 33-35.

Upper reservoirs 50, also known as melt chambers, are each designed to receive a supply of solid hot melt ink, referred to as ink "pucks". In preferred embodiments, the hot melt ink punks have a capacity of 150 cc, a melting point of between 60 and 70 degrees centigrade, and a viscosity of about 23 centipoise at a temperature of 135 degrees centigrade. However, hot melt inks with other characteristics may be used as well.

As discussed below with reference to Figures 29-31, the hot melt ink pucks are maintained solid in the respective upper reservoirs 50 until the chromatic characteristics of the solid hot melt inks are verified and until the corresponding lower reservoirs 52 have sufficient space to receive the additional supplies of hot melt ink without overflowing. Once both of these criteria are met for any single color of ink, the solid hot melt ink puck in the corresponding

upper reservoir 50 is melted and allowed to flow into the corresponding lower reservoir 52 where the hot melt ink is further heated to maintain it in a liquid or molten state so that it can be supplied to one of the ink jet heads upon demand.

Gear motor 1004 drives shaft 1007 continuously during ink supply system 24 operation. Clutch control 1040 controls each of cam links 1012A-1012D separately for selectively driving the corresponding pistons 1008A-1008D to pump ink from the corresponding lower reservoirs 52. Clutch control 1040 is preferably an electric clutch controlled by controller 1402 (shown in Figure 32).

Inks from lower reservoirs 52 are pumped either through corresponding ink filters 1024A-1024D and tubes 1028A-1028D to heads 84 and 86 for printing, or through corresponding tubes 1032A-1032D to drain 1036 for disposal of the ink. Filters 1024A-1024D are collectively referred to as filters 1024. Tubes 1028A-1028D and tubes 1032A-1032D are collectively referred to as tubes 1028 and tubes 1032, respectively. Each of filters 1024 filters a different one of the colors of ink before the ink is pumped through tubes 1028 to the ink jet heads.

In preferred embodiments in which printer 10 is a hot melt ink jet printer, tubes 1028 and 1032 are of the type which include a heating element (1029 and 1033, respectively, as shown in Figure 29) for selectively heating the ink within the tubes and thereby selectively maintaining the ink in a liquid state so that it may be pumped. Tubes 1028 and 1032 are frequently referred to as heated or heatable umbilical tubes. Inclusion of heatable tubes 1032 allows ink to be drained or purged from lower reservoirs 52 without all of the ink having to be ejected through the heads. This feature, which is discussed in greater detail with reference to Figure 29, saves both time and media and prolongs the life of ink jet heads 84 and 86.

Tubes 1028 and 1032 are capable of carrying ink pumped under pressure through the tubes when the pumping pressure does not exceed some maximum pressure. The nominal operating pressure is, for example,

approximately 50 to 60 psi for certain tubes. The maximum operating limit pressure is approximately 250 psi. A partially clogged or blocked ink filter can result in higher pumping pressures upstream from the filter. Therefore, placement of filters 1024 before or upstream of tubes 1028 helps to prevent damage to tubes 1028 caused by excessive pumping pressures. As described in connection with Figure 29, a relief valve is provided to relieve over-pressure conditions due to clogged tubes.

Figure 29 illustrates portions of ink supply system 24 in greater detail. For ease of illustration, upper and lower reservoirs 50A and 52A for only one color of ink are shown. The reservoir and pump system for the other colors of ink are substantially identical. Once again, the reservoir embodiment shown in Figure 29 is particularly adapted for hot melt ink jet printers. However, the inventive concepts disclosed can be applied by one skilled in the art to ink jet printers that use other types of ink, such as aqueous, semi-liquid and semi-solid inks. Embodiments of ink supply system 24 adapted for use with other types of ink are discussed later with reference to Figures 33-35.

In preferred embodiments, reservoir 50A is designed to receive a solid hot melt ink "puck". Upper reservoir or melt chamber 50A is preferably the same shape as the solid hot melt ink puck which will be added to the system by its insertion into reservoir 50A. The different colored ink pucks CMYK and corresponding upper reservoirs 50A-50D are keyed such that an ink puck of a particular color will only fit into the opening of the appropriate upper reservoir.

Upper reservoir 50A is preferably a cylindrical cup having tube or funnel section 1044 which extends into lower reservoir 52A to provide fluid communication between reservoir 50A and reservoir 52A when desired. In preferred embodiments, upper reservoir 50A is a drawn aluminum cup, the high thermal conductivity of which allows side walls 1048 to be easily heated to prevent build-up of re-solidified hot melt ink. Upper reservoir or melt chamber heater 1052 is preferably a 60 watt foil heater in electrical communication with controller 1402 (shown in Figure 32) through wires 1056 for selectively heating

upper reservoir 50A in order to melt the solid hot melt ink. Insulators 1060 and 1064 are formed from a heat insulating material and help to insulate upper reservoir 50A from heat generated during operation of lower reservoir 52A. Insulator 1060 is positioned immediately below heater 1052. Aluminum heat shunt plate 1068 is secured between insulator 1060 and insulator 1064 in order to dissipate heat energy emanating from lower reservoir 52A.

Lower reservoir 52A has side sections 1072 and a bottom section 1076. A lower reservoir heater 1080, which is in electrical communication with controller 1402 through wires 1084, is used to heat lower reservoir 52A to maintain hot melt ink in the lower reservoir in a liquid or molten state during printer operations. Fins 1088 protrude upwards from bottom section 1076 and provide increased dispersion of heat throughout the ink in lower reservoir 52A. Fins 1088 are positioned such that ink flow throughout each lower reservoir is not impeded.

In preferred embodiments, each of upper reservoirs 50A-50D have a separate heater 1052A-1052D so that solid hot melt ink in each of reservoirs 50A-50D may be melted individually upon demand. However, since hot melt ink in each of lower reservoirs 52A-52D is maintained in a liquid state during print operations so that ink may be readily supplied to the ink jet heads, lower reservoir heater 1080 can be a single heater of sufficient thickness and length so that it may be positioned adjacent bottom sections 1076 of each of the four lower reservoirs 52A-52D to provide heat thereto.

Defined within a side section 1072 of lower reservoir 52A is piston chamber 1092 having a known volume in which piston 1008 reciprocates when clutch control 1040 is engaged. Clutch control 1040, for each individual color station pump, is engaged by controller 1402 whenever ink level sensors (not shown in Figure 29) in the ink jet on-head reservoir indicate that ink levels are below some predetermined level and require replenishment.

Channel 1094 is defined in bottom section 1076 of lower reservoir 52A for carrying ink from the reservoir to chamber 1092 during backstrokes of

piston 1008. As piston 1008 is engaged in a backstroke to fill chamber 1092 with hot melt ink from lower reservoir 52A, liquid hot melt ink is drawn from reservoir 52A, through channel 1094 and check valve 1098, and into chamber 1092. When piston 1008 is engaged in a pumping stroke for pumping hot melt ink from piston chamber 1092, check valve 1098 blocks the flow of ink back into reservoir 52A.

During normal print operations, drain tubes 1032 are not heated so that ink in the tubes will solidify. The solidified ink provides back pressure which the positive displacement pump cannot overcome. Therefore, no ink flows through drain tubes 1032 during normal print head replenishment operations. With solidified ink and check valve 1098 preventing ink flow through drain tubes 1032 and channel 1094, respectively, hot melt ink from piston chamber 1092 flows through channel 1102 and past ball valve 1106 and into filter chamber 1110. Ball valve 1106 also prevents ink from being drawn back toward chamber 1092 during filling strokes of piston 1008.

Liquid hot melt ink flows through sintered stainless steel filter element 1114, entering filter element 1114 from 360 degrees. Filtered ink flows upward and eventually out of orifice 1118 and into filter chamber 1122. Ink is then forced under pressure from chamber 1122, through fitting channel 1126, and into heated supply tubes 1028 which carry the ink to the ink jet heads.

If filter 1024 becomes partially clogged, or if ink in supply tube 1028 is not sufficiently liquified, a back pressure results which could cause damage to tube 1028 and other system components. To prevent such damage, relief valve 1142 is included to provide an alternate path through which ink pumped from piston chamber 1092 can flow. Relief valve 1142 has a high breakdown pressure so that it does not allow ink to flow back into reservoir 52A during normal ink jet head ink replenishment operations. The breakdown pressure is preferably a pressure close to the pressure at which tubes 1028 and 1032 are known to incur damage. For example, in preferred embodiments, it is known that supply tubes 1028 and drain tube 1032 are damaged at pressures

above about 250 psi. In these embodiments, a breakdown pressure of about 150 psi is chosen for relief valve 1142 to protect the tubes.

Over time, when filter element 1114 becomes clogged due to particles removed from the ink during print head ink replenishment operations, hex bolt 1130 having threaded portion 1132 can be unfastened to clean or replace filter element 1114. O-rings 1134 provide a tight but removable seal for chamber 1122, which facilitates removal of the filter for cleaning or replacement. Electrically isolated fitting 1138 allows heater 1029 of ink supply tube 1028 to be powered without electrifying the other components of ink supply system 24. The location of fitting 1138 and fitting channel 1126 allows supply tube 1028 and drain tube 1023 to remain in place while filter 1024 is removed for cleaning or replacement.

Providing a filter remote and separate from the ink jet heads reduces clogging of the on-head filters. Since the on-head filters are usually integral components of standard ink jet heads, and because current designs require the entire ink jet head to be replaced when the on-head filter becomes clogged, off-head filter assembly 1024 prolongs ink jet head life expectancy, and in a resulting reduction in costs. This is particularly important for the high volume of ink used in graphics quality, large-format ink jet printing as is achieved with the printer of the present invention. Without off-head filter 1024, existing ink jet head designs would require frequent replacement when used in a high ink flow rate application. Additionally, as discussed above, placement of filters 1024 upstream from supply tubes 1028 prevents damage to tubes 1028 and allows ink to be supplied to the ink jet heads at a higher pressure. This in turn allows the ink jet heads to be replenished more quickly, which is important in large format high print rate printing. Additionally, placement of filter 1024 away from the ink jet heads prevents a user from accidentally misaligning the heads while replacing the filter. It is preferred that supply tube 1028 be at least ten inches in length to permit replacement of filter 1024 without tampering with the heads. Moreover, since the present invention particularly applies to large-format

printers, supply tube 1028 is included in the umbilical connections 120 to the heads, and are of a length adequate to permit the head to travel across the 54 inch wide printing medium and the park zone.

In preferred embodiments, lower reservoir 52A has at least twice the ink storage capacity of upper reservoir 50A. For example, in the embodiment shown in Figure 29, lower reservoir 52A is a 300 cc reservoir, while upper reservoir 50A is a 150 cc reservoir. The large ink storage capacities of reservoirs 50A and 52A are important to accommodate the high rate of ink usage which occurs in high resolution, high print rate, large format printing which is achievable with printer 10 of the present invention.

Level sensor 1146 is positioned within side section 1072 of lower reservoir 52A for determining whether ink in lower reservoir 52A has fallen to a level such that there is sufficient capacity in reservoir 52A to hold another melted ink puck without overflowing. In preferred embodiments, level sensor 1146 is a thermistor which electrically communicates with controller 1402 through wires 1150. Controller 1402 monitors the rate of heat transfer to determine if the ink level in lower reservoir 52A has fallen below the level of sensor 1146. If level sensor 1146 is positioned in this manner, such that it can be used to determine when there is available storage capacity in lower reservoir 52A, then an entire ink puck may be melted without overflowing lower reservoir 52A.

Controller 1402 controls upper reservoir heater 1052 such that an ink puck in upper reservoir 50A begins to melt as soon as, but not before, there is sufficient capacity in lower reservoir 52A. This feature of the present invention provides several important advantages. First, it saves time and costs which would be associated with clean-up and maintenance of supply system 24 should lower reservoir 52A overflow during an ink replenishment operation. Second, it saves costs by reducing or eliminating lost ink. Finally, it provides the capability to add large quantities of ink to the reservoir system without stopping printing operations. This is very important due to the large quantities

of ink used in the printing applications possible with printer 10 of the present invention. To achieve the high-resolution, high-speed, large format printing capable with the present invention, the ink supply system must be able to both receive fresh supplies of ink for storing and to replenish as required the ink jet heads with ink while the ink jet heads are printing. This "on-demand" ink replenishment capability does not exist in prior art ink jet printers.

Upper reservoir 50A includes temperature sensor 1154 embedded in or attached to the cup. Temperature sensor 1154 communicates with controller 1402 through wires 1158. Lower reservoir 52A includes a temperature sensor 1162 embedded in bottom section 1076. Temperature sensor 1162 communicates with controller 1402 through wires 1166. Temperature sensors 1154 and 1162 provide temperature information to controller 1402 which allows controller 1402 regulate the duty cycle or on-time of heaters 1052 and 1080, respectively, to maintain predetermined temperatures in upper reservoir 50A and lower reservoir 52A.

Some important operational aspects of ink supply system 24 are described next with reference to Figures 29 and 32. However, these operational aspects can be altered slightly to obtain the benefits of profiler system 48, which is described below in greater detail with reference to Figure 30. In preferred embodiments of the present invention, during normal operation, heater 1033 of ink drain tube 1032 is controlled by controller 1402 so that ink in tube 1032 solidifies. Controller 1402 causes heater 1029 of ink supply tube 1028 to cool such that hot melt ink in tube 1028 obtains a more viscous consistency. Ink in tube 1028 is not allowed to completely solidify so that, upon demand, ink may be quickly supplied to the on-head reservoir of an ink jet head. Alternatively, heater 1029 may be controlled to an appropriate temperature for long periods of time to maintain the ink in tube 1028 in a ready fluid state.

When the ink level sensor (not shown) in the on-head reservoir indicates that the level of ink in the on-head reservoir is below some predetermined point (that the volume of ink in the on-head reservoir available

for printing is low), print head system 26 communicates this information to controller 1402. Controller 1402 then causes heater 1029 to heat supply tube 1028 so that the ink in tube 1028 liquifies, thus achieving a lower viscosity. As soon as ink in supply tube 1028 is sufficiently liquified, controller 1402 operates clutch 1040 to operate piston 1008 to pump ink from reservoir 52 through supply tube 1028 to the on-head reservoir in supply 100. As described above, between piston chamber 1092 and tube 1028, the ink passes through channel 1102 and off-head filter 1014. As the ink passes through filter element 1114, impurities and other foreign matter are removed from the ink. Once the level sensor in the on-head reservoir indicates that sufficient ink has been admitted to the on-head reservoir to replenish the on-head supply, supply tube 1028 is once again allowed to cool to the point that the ink becomes more viscous. By maintaining the ink in a semi-solid/semi-liquid condition, ink supply system 24 can quickly supply ink to the ink jet heads while still benefitting from a reduction in operating costs resulting from a savings in energy. While even more energy could be saved by allowing the ink to completely solidify, the resulting increase in time needed to resupply the heads with ink is unacceptable for the ink usage rates of the present invention.

As discussed previously, when level sensors 1146 indicate that the quantity of ink in any of lower reservoirs 52 has fallen below a predetermined level, controller 1402 causes the appropriate heater 1052 to melt the solid hot melt ink puck in the corresponding upper reservoir 50, thereby replenishing the supply of ink in the corresponding lower reservoir 52. As is discussed below with reference to Figure 30, controller 1402 also verifies that the chromatic characteristics of the ink puck match predetermined characteristics before melting the solid hot melt ink and introducing that ink into the ink currently available to printer 10.

Because ink in upper reservoirs 50 is in a solid state, it is difficult to determine the quantities of ink in an upper reservoir 50 after melting has begun. Since the ink drains into lower reservoir 52 upon melting, a typical level

sensor cannot be used. As a result, predicting when controller 1402 should turn off power to a particular upper reservoir heater 1052 is difficult. Ink supply system 24 overcomes this difficulty by monitoring temperature sensor 1154 of each upper reservoir 50. While melting the solid hot melt ink puck, controller 1402 monitors the temperature with temperature sensor 1154 to control the duty cycle or on-time of heater 1052 so that the temperature does not rise above a predetermined level. When all of the ink has melted and drained into lower reservoir 52, the temperature sensed by temperature sensor 1154 will rise quickly each time heater 1052 is turned on. If the temperature rises too quickly, as determined by controller 1402 by a comparison to a predetermined rate of temperature increase, controller 1402 determines that the ink puck has been melted and turns heater 1052 off until such time as another ink puck has been introduced into upper reservoir 50 and is to be melted.

In certain circumstances, such as when contamination of the ink supply occurs or when a new ink with a different formulation as the present ink is introduced, ink in lower reservoir 52 must be drained or purged from the system. In prior art ink delivery systems, purging of ink from the reservoirs required the ink be pumped to the head and ejected through the ink jet nozzles. This is an undesirable method of purging ink because it is time-consuming and it reduces the life expectancy of the ink jet heads. The present invention provides for purging the reservoirs in minimal time and with minimal effect on ink jet life expectancy. Controller 1402 turns off heater 1029 so that ink in tube 1028 solidifies. Controller 1402 next turns on heater 1033 so that ink in tube 1032 liquifies. Then, as piston 1008 pumps, ink is pumped through channel 1102 and tube 1032 to drain 1036. Once reservoir 52 is empty, controller 1402 turns off heater 1033 and turns on heater 1029 to reliquify ink in supply tube 1028. Then, piston 1008 pumps ink remaining in supply tube 1028 through the ink jet head. Upon reintroduction of ink into now-cool drain tube 1033, that ink will solidify, closing the drain. The result of this process is that ink is quickly pumped to the drain or waste reservoir and minimal ink is purged through the

ink jets.

Figure 30 is a perspective view of portions of ink profiler system 48. Ink profiler system 48 includes docking station 1200 and profiler modules 1210A-1210D. Additionally, profiler system 48 includes controller 1402 (shown in Figure 32) which, in preferred embodiments, is the same controller that controls other operations of printer 10. Docking station 1200 includes circuit board 1214, connectors 1218A-1218D corresponding to the four colors (CMYK) mounted on circuit board 1214, and flexible cable 1222 which provides electrical communication between controller 1402 and profiler modules 1210.

Each profiler module 1210A-1210B corresponds to a separate one of the four primary ink colors and includes a plastic casing 1230 and a circuit board 1234. Circuit board 1234 supports standard integrated and discrete TTL circuitry and non-volatile memory devices which provide information to, and receive information from, controller 1402. In other embodiments, the memory devices can be powered by a self-contained battery. In preferred embodiments, the memory devices mounted on circuit board 1234 are Electrically Erasable Programmable Read Only Memory (EEPROM) devices which are capable of serial communication with controller 1402 through corresponding connectors 1218.

A profiler module accompanies each new supply or puck of ink. When a new puck of ink is inserted into one of upper reservoirs 50, the accompanying profiler module is plugged into the corresponding connector 1218 of docking station 1200. The memory devices in each profiler module 1210 contain information indicative of both the quantity and the chromatic characteristics of the new supply of ink. Using this information, the controller can verify that the chromatic characteristics of the new supply of ink are proper for the intended application before allowing the new supply of ink to pass from the particular upper reservoir 50 to the corresponding lower reservoir 52.

If the chromatic characteristics of the ink do not match or are not substantially the same as a predetermined set of chromatic characteristics stored

in the memory of controller 1402, or if they do not fall within a predetermined range of chromatic characteristics, the controller will provide an error signal to the system operator on output device 1406 indicating that a non-profiled ink has been added to the system. This allows the operator to remove the non-profiled supply of ink from the upper reservoir without contaminating the existing supply of profiled ink already in the lower reservoir. Thus, the non-matching ink is not delivered to the ink jet head. This feature is necessary to maintain quality control of the chromatic characteristics of the inks used by the ink jet printer, which in turn, is extremely important in ensuring that the color quality of the printed output closely matches the desired color quality. It also prevents the contamination of ink in lower reservoirs 52, which in turn, saves time and costs associated with purging the contaminated ink from the system. Controller 1402 can write to the memory devices in modules 1210 to alter or update the information stored in these devices. This allows the controller to change an access code or alter the information in a way that will prohibit a module 1210 from being used again with a non-profiled supply of ink, thereby ensuring quality control of the print operation.

Controller 1402 can obtain specific chromatic characteristics information about a particular supply of ink in a number of ways. For example, the memory devices in profiler modules 1210 can contain specific and detailed information about the chromatic characteristics of the ink. Controller 1402 can then compare this detailed information to information stored in its associated controller memory. In an alternative embodiment, profiler modules 1210 can contain less detailed information such as the ink's color and quantity. Controller 1402 would then verify that the color of the ink is correct for the particular upper reservoir 50, and that the lot number or date code matches inks currently being used in printer 10, or one from an acceptable list of lot numbers or date codes stored in the memory of controller 1402. Specific chromatic characteristics could then be obtained, if necessary, from look-up tables in the memory of controller 1402.

In addition to verifying the chromatic characteristics of the new supply of ink introduced into an upper reservoir 50, the information related to quantities of ink stored in the profiler module memory units provides a number of advantages over prior art ink supply systems. First, this information allows controller 1402 to verify that there is sufficient capacity in lower reservoir 52 to receive the new supply of ink from corresponding upper reservoir 50. With this information available, ink supplies can be added to the system without concern for whether there is insufficient space available in the lower reservoir. Additionally, this allows the controller 1402 to monitor ink quantities already in the system.

Controller 1402 continuously or periodically monitors the available quantity of ink in the system as follows. As profiled ink pucks are added to upper reservoir 50A, controller 1402 updates a register or memory location which contains information on the total quantity of ink in the system. Determining the quantity of ink that has been expelled from the system through the ink jet heads can be done in several ways. First, a normalized volume of ink expelled each time an ink jet nozzle fires can be determined. Then, each time the ink jet nozzle fires, the normalized volume can be subtracted from the total quantity of ink in the system. The register can then be updated with a new total quantity of ink in the system. A second method of determining the quantity of ink in the system is to count the number of strokes of piston 1008 in chamber 1092 during engagement of clutch 1040 for each respective color of ink. Then, because the volume of chamber 1092 is known, the quantity of ink pumped by the system can be determined and the total quantity information updated in the register memory. In any method of determining the total quantity of ink used by the system, an adjustment factor may be introduced to ensure that the total quantity used by the printer has not been underestimated.

Monitoring ink quantities in the system allows controller 1402 to forecast the amount of ink needed for a print job and to inform the user if there is insufficient ink available in the reservoir system to print the job. This

prevents the user from beginning a very large print job, such as a 30-foot banner, and having to add ink during the print job. However, if ink does need to be added during the print job, controller 1402 will use level sensor 1146 to identify this condition and inform the user that more ink is needed.

Another advantage of monitoring ink quantities is that this process lets the user know if unprofiled ink has been introduced into the system. Since each quantity of new ink is validated by its profiler, which informs the system software that a new quantity of ink is available, a total quantity of profiled ink is kept in the memory of controller 1402. Once unprofiled inks have been determined to have been introduced into the system, the user may be informed that the unprofiled inks may adversely affect the ability of printer 10 to accurately control color quantity in the printed output.

Figure 31 illustrates an interface circuit for use with controller 1402 for determining whether one or more of supply tubes 1028 and drain tubes 1032 is disconnected and for controlling the application of power to heaters 1029 and 1033 for melting hot melt ink within the respective tubes. In circuit 1300, resistance R_H represents the resistance of the heating element in one of heatable tubes 1028A-1028D or 1032A-1032D. Load R_H is connected to a power supply through a field effect transistor (FET) Q_1 which acts as a switch to selectively connect and disconnect load R_H from power supply V_{CC}. A first electrode 1308 of switch Q_1 is connected to power supply V_{CC}. A second electrode 1312 of switch Q_1 is connected to load R_H. Control electrode 1316 of switch Q_1 is connected to controller 1402 which provides control signals for selectively turning switch Q_1 on and thereby controlling application of power to the heater (R_H) of the particular supply or drain tube monitored.

A first resistor R_1 is connected between electrodes 1308 and 1312 of switch Q_1. A second resistor R_2 is connected between electrode 1312 of switch Q_1 and ground. Electrode 1312 is also connected to an analog to digital (A/D) converter 1304 which provides digital information to controller 1402 which is indicative of voltage V_T applied to the tube heaters. In preferred

embodiments, the resistances of R_1 and R_2 are approximately equal and both are much greater than the resistance of R_H.

Typically, a controller generates a control signal to cause power to be applied to a heater in a particular ink supply tube 1028 or drain tube 1032. After a predetermined period of time it may be assumed that ink in the tube has melted and ink is subsequently pumped through the tube. However, it is possible that one or more of tubes 1028 and 1032 could become disconnected. Absent the monitoring for this disconnected condition, ink would inevitably be pumped to a tube which is disconnected and thus unable to receive the flow of ink. This results in waste, clean-up, and potential damage to the printer.

Circuit 1300 provides for detection of whether a particular tube is connected or disconnected before power is applied to the tube heater and before ink is pumped to the tube. When switch Q_1 is off and the tube is connected, voltage V_T across load R_H will be approximately 0 volts because of the voltage division between R_1 and the parallel combination of R_2 and R_H. If switch Q_1 is off and the tube is disconnected so that R_H is not electrically connected to circuit 1300, V_T will be one half of V_{CC} because of the equal voltage division between R_1 and R_2. When the tube is connected and switch Q_1 is on, load R_H is powered by a full V_{CC}. Therefore, in order to ensure that ink is never pumped to a disconnected tube, controller 1402 monitors the output of A/D converter 1304 for a V_T value of one half V_{CC}. In an alternative embodiment, any value substantially greater than 0 volts provides an indication that a tube is disconnected. In this instance, power is never applied to the tube's heater and ink is never pumped to the tube. Controller 1402 generates an error message to alert the system operator.

Figure 32 shows one embodiment of a control system 1400 which monitors and controls operation of printer 10 in the various manners described above. Control system 1400 includes controller 1402, input device 1404, output device 1406, ink profiler 48, paper profiler 530, upper reservoir heaters 1052, upper reservoir temperature sensors 1154, lower reservoir heater 1080, lower

reservoir temperature sensor 1162, lower reservoir level sensors 1146, on-head heaters 112, head supply tube heater 1029, ink purge tube heater 1033, print head system 26, paper handling system 24, clutch 1040, on-head reservoir level sensor 100, media heater/quencher system 516, 518 and heatable tube verification circuit 1300. For ease of illustration verification circuit 1300 and supply tube heaters 1209 and 1033 are each shown to be independently connected to controller 1402. However, in some embodiments, heaters 1209 and 1033 are connected to controller 1402 only through circuit 1300.

Controller 1402 is preferably a microprocessor-based computer including associated memory and associated input/output circuitry. However, in other preferred embodiments, controller 1402 can be a programmable logic controller (PLC) or other digital circuitry suited for monitoring and controlling operation of printer 10.

Input device 1404 can be any of a number of suitable mechanisms for a user or another computer-based system to provide information to controller 1402. For example, in preferred embodiments, input device 1404 can be a keypad data entry device, a keyboard or a remote program device.

Output device 1406 can also take a variety of forms. For example, output device 1406 can include a display output such as a cathode ray tube or a liquid crystal display. Output device 1406 can also be a printer, or a communication device which transmits the output of controller 1402 to another computer-based system which may monitor or control the overall operation in which control system 1400 and printer 10 are used.

As discussed above, paper profiler is a non-volatile memory that contains information concerning the printing medium. This information is provided to controller 1402 for the purposes described above in Section II, "Paper Handling System". Also as discussed above in Section II, the media heater/quencher system 516, 518 is controlled by controller 1402 to perform post printing operations on the printed medium. Heater 516 is controlled by controller 1402. In the preferred embodiment, quencher 518 is an air-cooled

quencher, so no direct connection is required to controller 1402. Alternatively, if quencher 516 is a liquid-cooled or other quencher, the flow-rate of cooling liquid through the quencher is controlled by controller 1402 to maintain quencher temperature within a desired range.

The preferred embodiments of the present invention thus far described have been particularly adapted for hot melt ink jet printers. However, many of the advantageous features described thus far are equally applicable to other types of ink jet printers. For instance, the prescreening of ink introduced into the system made possible by the two stage ink delivery system and profiler can be adapted for use with other types of inks. Similarly, the off-head ink pre-filtering aspects of the present invention are applicable to ink supply systems adapted for handling other types of ink. Still other aspects of the present invention, such as the use of a relief valve to prevent damage to the ink supply tubes and the use of drain tubes to selectively drain the reservoirs without pumping the ink to the ink jet head are equally applicable to other types of ink jet printers.

Figures 33 and 34 illustrate a modified ink supply system in accordance with the embodiments of the present invention which is adapted for ink jet printers using non-hot melt inks such as aqueous inks, semi-liquid inks and semi-solid inks. The embodiments thus far described have utilized the change in phase that occurs in hot melt inks to allow prescreening of new ink supplies introduced into the system using the two stage reservoir. The solid hot melt ink is not melted until the chromatic characteristics of the ink have been verified and the lower reservoir has sufficient space to hold the additional ink. In order to use a two-stage reservoir system to prescreen these other types of ink, a controllable valve mechanism is needed to prevent introduction of ink from upper reservoirs 50 into lower reservoirs 52 before controller 1402 verifies that there is sufficient capacity available in reservoir 52 to receive the additional ink and that the chromatic characteristics are appropriate.

Figures 33 and 34 illustrate an ink supply system having valve

or gate mechanism 1500 which controls the passage of ink between upper reservoir 50 and lower reservoir 52. For purposes of this embodiment, upper reservoir 50 is a container for the ink and includes a mechanism for transporting the ink to the lower reservoir. For example, in the case of liquid and semi-liquid inks, upper reservoir may simply comprise an inverted bottle in which the ink is supplied, allowing gravity to transport the ink through valve 1500 to the lower reservoir. In the case of a semi-solid ink, the upper reservoir may comprise a squeezable tube containing the ink, in which case a mechanism is provided to squeeze the tube to transport the ink though valve 1500 to the lower reservoir. In any case, four separate valves or gates 1500A-1500D are used, one for each color of ink. Valve 1500 includes access cover 1510 which has an access hole 1520 extending therethrough, solenoid 1530, and pivot pin 1540. Valve 1500 is positioned between upper reservoir 50 and lower reservoir 52, and over fill hole 1550 in lower reservoir 52.

When a new supply of ink is added to a particular upper reservoir, controller 1402 uses profiler information to verify the chromatic characteristics of the ink and to ensure that lower reservoir 52 has sufficient capacity to accept the new supply of ink. Once sufficient capacity and the chromatic characteristics have been verified, controller 1402 operates solenoid 1530 to rotate access cover 1510 about pivot pin 1540 so that access hole 1520 aligns with fill hole 1550. Once aligned, the new supply of ink can be introduced into lower reservoir 52, as described above. With some types of ink, such as semi-solid inks, the printer operator may be required at this time to squeeze the upper reservoir to force the new supply through hole 150 into lower reservoir 52. Alternatively, controller 1402 may operate a mechanical device to squeeze the tube containing the semi-solid ink. For example, an accordion-style squeeze tube having collapsible walls may provide the semi-solid ink, and an operator may receive the squeeze tube to compress the tube and collapse the walls to remove the ink therefrom.

Pump 1560 pumps ink from lower reservoir 52 through supply tubes 1028 to print heads 84 and 86 in a manner very similar to that described

above for hot melt ink jet printers. For some types of inks, pump 1560 is preferably a positive displacement pump. However, in other embodiments, other types of pumps can be used as well. Supply tubes 1028 will not, in some embodiments, need to be heated supply tubes. However, in other embodiments such as those using highly viscous semi-solid inks, heating tubes 1208 will aid in reducing the viscosity of the ink, and thus will remain a preferred embodiment.

Controller 1402 may optionally additionally control a post-image processing device 1600 such as illustrated in Figure 35. Device 1600 provides ultraviolet (UV) curing of semi-liquid and semi-solid inks after they have been deposited on a print medium. Device 1600 includes printer carriage 1610 which support ink jet heads 84 and 86. The ink jet heads deposit droplets 1620 of one of the above-described inks on a print medium 1630 as carriage 1610 passes across the page. UV wave generating device 1640 is attached to carriage 1610 and follows carriage 1610 as it passes over the print medium. As UV device 1640 produces UV waves, ink droplets 1620 under device 1640 are hardened at their present position on medium 1630.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, the invention has been described with respect to four color printing systems (cyan, magenta, yellow and black), but could easily be adapted for three color printing systems (red, green and blue) or for other colors, including continuous-tone ("contone") color printing systems and "high-fidelity" color printing systems having as many as eight or more colors (e.g., CMYKOGVP). While the above detailed description and accompanying drawings set forth preferred embodiments, this disclosure presents illustrative embodiments of the present invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art which fall within the

scope and spirit of the principles of this invention.

WHAT IS CLAIMED IS:

1. An ink delivery system (24) for delivering ink to an ink jet head (84) which applies ink to a large format print medium (28), the ink delivery system characterized by:

a receiving means (24), connected to an ink jet head (84), for receiving a supply of ink, the supply of ink having chromatic characteristics associated therewith;

an ink profiler associated with the supply of ink for providing information indicative of characteristics associated with the supply of ink; and

a controller (1402) coupled to the ink profiler for controlling operation of the receiving means as a function of the information provided by the ink profiler.

2. The ink delivery system of claim 1 wherein the receiving means includes a first off-head reservoir (50) receiving the supply of ink and a second off-head reservoir (52) in fluid communication with the first off-head reservoir (50), and wherein the ink jet head includes an on-head reservoir (100) in fluid communication with the second off-head reservoir (52), the controller (1402) being responsive to a predetermined level of ink in the on-head reservoir (100) to operate the second off-head reservoir (52) to supply ink to the on-head reservoir (100).

3. The ink delivery system of claim 2 further including a piston chamber connected to the second off-head reservoir (52), a piston movable within the piston chamber for pumping ink from the second off-head reservoir (52), an ink filter (1114) coupled to the piston chamber for filtering ink pumped from the second off-head reservoir (52), and a supply tube (1028) for providing fluid connection between the ink filter (1114) and the on-head reservoir (100) so

that ink may be pumped from the second off-head reservoir (52) to the on-head reservoir (100) upon demand.

4. The ink delivery system of claim 2 further including a level detector associated with the second off-head reservoir (52) for determining a level of ink in the second off-head reservoir (52), the level of ink in the second off-head reservoir (52) being indicative of a capacity of the second off-head reservoir (52) to receive a quantity of ink from the first off-head reservoir (50) without overflowing, wherein the controller (1402) controls operation of the first off-head reservoir (50) such that the second off-head reservoir (52) does not receive the supply of ink from the first off-head reservoir (50) if the second off-head reservoir (52) does not have sufficient capacity to receive the quantity of ink in the first off-head reservoir (50).

5. The ink delivery system of claim 2 including a pump (1020) for pumping ink from the second off-head reservoir (52) to the on-head reservoir (100) and either a check valve (or a relief valve (1142) disposed between the second off-head reservoir (52) and the pump (1020).

6. The ink delivery system of claim 2 wherein the controller (1402) controls operation of the ink jet head by controlling deposition of ink at specific pixel locations as a function of the chromatic characteristics of the supply of ink.

7. The ink delivery system of claim 1 further including a supply tube (1028) providing fluid communication between the receiving means (14)and the ink jet head, and continuity checking means (1300) for checking the continuity of the supply tube (1028) disposed between the receiving means and the ink jet head (84).

8. A printing medium (28) handling apparatus characterized by:

a frame (14);

a printing medium (28) supply assembly releasably attached to the frame (14), the supply assembly carrying a supply of a printing medium (28) having printing medium characteristics;

at least one print head (84);

a printing medium (28) advancement mechanism for advancing the printing medium (28) past the print head (84);

a first printing medium (28) take-up mechanism for collecting printing medium (28) after it has passed the print head (84);

a heater (46) for heating the printing medium (28) after it has been collected by the first take-up mechanism;

a second printing medium (28) take-up mechanism for advancing the printing medium (28) past the heater (46) and collecting the heated printing medium (28);

wherein the printing medium (28) supply assembly, print head (84), printing medium (28) advancement mechanism, first take-up mechanism, heater (46), and second take-up mechanism are configured and arranged on the frame to allow printing medium (28) to move consecutively from the printing medium (28) supply assembly past the print head (84) and onto the first take-up mechanism, and then from the first take-up mechanism past the heater (46) and onto second take-up mechanism;

at least one memory unit adapted for storing information indicative of the characteristics associated with a plurality of types of printing medium (28); and

a controller (532) electrically connected to the memory unit, the print head, the printing medium (28) advancement

mechanism, the first take-up mechanism, the heater (46), and the second take-up mechanism, for operating the print head (84), printing medium (28) advancement mechanism, first take-up mechanism, heater (46), and second take-up mechanism based on the information supplied by the memory unit.

9. The apparatus of claim 8, further characterized by:

a tensioning apparatus for tensioning printing medium (28) moved past a print head between a printing medium (28) take-up spool and a printing medium (28) supply, the tensioning apparatus further including:

a spring for applying a selected rotational force to the first printing medium take-up mechanism (34) for maintaining printing medium (28) tension between the printing medium (28) supply and a take-up pool within a predetermined tension range, the spring providing rotational force that is related to spring displacement;

an actuator connected to the spring for providing spring displacement for providing the selected rotational force; and

a second controller (532) for determining the selected rotational force to compensate for changes in the diameter of the printing medium (28) take-up spool and activating the actuator, thereby maintaining a substantially constant tension between the printing medium (28) take-up spool and the printing medium (28) supply.

10. The apparatus of claim 9, wherein the second controller (532) is adapted to monitor the amount of printing medium (28) wound about the take-up

spool and adjust the force applied to the take-up spool as the diameter of the printing medium (28) on the take-up spool changes.

11. The apparatus of claim 9, further characterized by:

a printing medium profiler (530) associated with the supply of printing medium (28) for providing information related to the printing characteristics associated with the supply of printing medium (28); wherein

the controller (532) is coupled to the printing medium profiler (530) for selecting the rotational force to compensate for changes in the diameter of the printing medium (28) on the take-up spool and activating the actuator as a function of the information provided by the printing medium profiler (530).

12. The apparatus of claim 9, wherein the spring is connected to a longitudinal drive shaft for continuously exerting a selected rotational force on the drive shaft, the force exerted by the spring mechanism thereby causing the drive shaft to rotate about its longitudinal axis, a first end to the drive shaft communicating with the take-up spool such that rotation of the drive shaft causes rotation of the take-up spool about its longitudinal axis, and wherein the actuator comprises a drive motor, and wherein the second controller (532) is electrically connected to the drive motor for selectively operating the drive motor to adjust the spring displacement, thereby maintaining a substantially constant tension in the printing medium (28).

13. The apparatus of claim 12, wherein an input to the second controller (532) includes an drive shaft indexing input for monitoring the rotation of the drive shaft.

14. The apparatus of claim 13, wherein the second controller (532) is adapted for monitoring the amount of printing medium (28) wound about the take-up spool and adjusting the force exerted by the spring as the radius of the printing medium (28) on the take-up spool changes, thereby maintaining a substantially constant tension in the printing medium (28).

15. The apparatus of claim 9, further characterized by a second print head (86) having a plurality of piezo-electric ink jets (98), the print head (84) and the second print head (86) mounted on a carriage (60) so that both the print head (84) and the second print head (86) travel in the x-direction relative to the printing medium (28).

16. The apparatus of claim 15, further characterized in that:

the print head (84) has a plurality of ink jets (98) of a first color and a plurality of ink jets (98) of a second color, and

the second print head (86) has a plurality of ink jets (98) of a third color and a plurality of ink jets (98) of a fourth color.

17. The apparatus of claim 16, given further that a y-direction is defined perpendicular to the x-direction, and further characterized in that the print head (84) and the second print head (86) are offset in the x-direction and not offset in the y-direction.

18. The apparatus of claim 17, further characterized by a electronic processing apparatus coupled to the controller (1402) for adjusting the amount of each color of ink printed based on the direction of the first and the second print head (84,86) are traveling;

wherein the first and second print heads (84,86) print upon the printing medium (28) in both the positive x-direction and

the negative x-direction; and

wherein the first and second print heads (84,86) print in a preselected sequence over a particular pixel position on the printing medium (28) of either: first color, third color, second color, fourth color; OR third color, first color, fourth color, second color.

19. The apparatus of claim 16, and given a y-direction defined perpendicular to the x-direction, characterized in that the print head (84) and the second print head (86) are offset in the x-direction and offset in the y-direction with respect to each other.

20. The apparatus of claim 19, further characterized in that:

each color of ink utilizes the same number of ink jets (98),

each of the like-colored ink jets (98) are uniformly spaced in the y-direction with a y-distance between adjacent like-colored ink jets (98), and

the offset between the print head (84) and the second print head (86) in the y-direction is equal to the number of ink jets (98) for each color ink multiplied by the y-distance between like-color jets.

21. The apparatus of claim 20, further characterized in that:

the second color is yellow, the third color is black,

wherein the first and second print heads (84,86) print when traveling in both the positive x-direction and the negative x-direction, and

wherein the preselected sequence of printing a pixel position upon the printing medium (28) is either: first color, yellow, black, fourth color; OR first color, black, yellow, fourth

color.

22. The apparatus of claim 15, wherein:

the print head has a plurality of ink jets (98) of a first color;

the second print head has a plurality of ink jets (98) of a second color;

a y-direction is defined perpendicular to the x-direction, and

the print head (84) and the second print head (86) are offset in the x-direction and offset in the y-direction; and

the offset between the print head (84) and the second print head (86) in the y-direction is equal to one pixel.

23. An ink jet printer for printing on a large format printing medium (28), the ink jet printer comprising:

a support housing (14);

a printing medium (28) transport system which advances a printing medium (28) in a y-direction, the printing medium (28) transport system being carried by the support housing (14);

a rail structure (62) having two ends with a rail (82) running in an x-direction perpendicular to the y-direction and across the printing medium (28), the rail structure (62) being supported at both ends by the support housing (14) and removably coupled to the rail (82);

a carriage (60) supported entirely by the rail (82) and moveable in the x-direction in excess of 17 inches;

a carriage drive system (64) to move the carriage (60) in the x-direction; and

a print head supported by the carriage (60) adjacent the printing medium (28).

24. The ink jet printer of claim 23, wherein the carriage (60) further includes a first roller riding on a first side of the rail (82), a plurality of spaced second rollers (90) opposed to the first roller and riding on a second side of the rail (82); and wherein each of the rollers (90) rotates to thereby define an axis and has a tread providing axial support to the roller (90) to thereby secure the carriage (60) about the rail (82).

25. The ink jet printer of claim 24, wherein the rail (82) is further characterized by:

a first bearing side defining a v-shaped first roller path, wherein the tread of the first roller has an opposing v-shape that follows the first roller path; and

a second bearing side opposite to the first bearing side and defining a v-shaped second roller path parallel to the first roller path, wherein the treads of each of the second rollers has an opposing v-shape that follows the second roller path.

26. The ink jet printer of claim 23, wherein the rail (82) is characterized by:

a first bearing side defining a first roller path, wherein the tread of the first roller follows the first roller path; and

a second bearing side spaced from the first bearing side in the y-direction, the second bearing side defining a second roller path parallel to the first roller path, wherein the treads of each of the second rollers (90) follow the second roller path,

further including a stiffener bar having a support width in the y-direction which is more than twice the space between the first bearing side and the second bearing side.

27. The ink jet printer of claim 26, wherein the stiffener bar is further characterized by a z-stiffening portion extending outwardly in a z-direction perpendicular both to the x-direction and to the y-direction.

28. The ink jet printer of claim 23, wherein the x-direction and the y-direction define an x-y plane which is canted 10 to 30 degrees from vertical.

29. The ink jet printer of claim 23, further characterized by:

a transport system for advancing the printing medium (28) with respect to the print head (84) a distance in a y-direction of travel, wherein the ink jets (98) have a uniform y-component spacing in the y-direction of travel, each ink jet (98) being spaced from an adjacent ink jet at a y-component in the y-direction of more than 2 pixels.

30. The ink jet printer of claim 29, further characterized by:

the ink jets (98) being linearly arranged on the print head (84), and wherein the linear arrangement of ink jets (98) is canted 29 to 30 degrees to the x-direction.

31. The ink jet printer of claim 29 wherein each ink jet is spaced from an adjacent ink jet at an x component in the x-direction of 7 pixels and at a y component in the y-direction of 4 pixels.

32. The ink jet printer of claim 29 wherein the printing medium (28) is advanced in a series of non-uniform distances.

33. The ink jet printer of claim 32, wherein the number of linearly arranged ink jets (98) in each color is 48, and each repeating series is made up of advances of the printing medium (28) of 49, 49, 45 and 49 pixels.

34. The ink jet printer of claim 32, wherein the plurality of linearly arranged ink jets (98) comprise:

a number of linearly arranged ink jets (98) in each of a plurality of ink colors;

wherein each series is made up of two advances of the printing medium (28), and

wherein the total distance of advance from the series is equal to the number of jets in each color times two pixels.

35. The ink jet printer of claim 34, wherein the number of linearly arranged ink jets (98) in each color is 48, and each repeating series is made up of advances of the printing medium (28) of 49 and 47 pixels.

36. The ink jet printer of claim 29 wherein the ink jets (98) are linearly arranged, and

the linear arrangement of ink jets (98) is canted 13 to 15 degrees to the x-direction.

37. The ink jet printer of claim 29 wherein each ink jet (98) is spaced from an adjacent ink jet (98) at an x component in the x-direction of 8 pixels and at a y component in the y-direction of 2 pixels.

38. A process for printing upon a large format printing medium (28) with the ink jet printer (10) of claim 23, characterized by the steps of:

reading an input pulse indicative of the location of print head (84);

adjusting timing of the input pulse based on a parameter of the printer (10), thereby creating an adjusted pulse; and

printing with the print head (84) according to timing of the adjusted pulse.

39. The process of claim 38, wherein the input pulse is a binary signal generated by an encoder strip reader (106).

40. The process of claim 39, further characterized by the steps of:
reading a second input pulse indicative of the location of the print head (84);
comparing the input pulse and the second input pulse to determine location of the print head and direction of print head travel; and
selecting a pattern to be printed based on location of the print head (84) and direction of print head travel;
wherein the print head (84) prints the pattern according to timing of the adjusted pulse.

41. The process of claim 39, wherein the input pulse timing is determined based only on leading edges read by the encoder strip reader (106).

42. The process of claim 41, wherein the input pulse timing is interpolated such that the adjusted pulse has multiple changes for each leading edge.

43. The process of claim 2, wherein the input pulse timing is determined based only on trailing edges read by the encoder strip reader.

44. The process of claim 38, wherein the parameter of the printer is velocity error in travel of the print head (84).

45. The process of claim 44, further characterized by the steps of:
computing an instantaneous velocity of the print head (84) based on comparing the input pulse to a timer; and

determining the velocity error as the difference between instantaneous velocity and a desired velocity profile.

46. The process of claim 44, further characterized by the steps of:

computing a velocity profile based on comparing input pulse during a first pass of the print head to a timer; and

determining the velocity error as the difference between the velocity profile and a desired velocity profile, the velocity error being for use during a subsequent pass of the print head (84).

47. The process of claim 38, wherein the parameter of the printer is a direction of travel of the print head (84).

48. The process of claim 38 for use with a printer having a second print head (86) moving with the print head, further characterized by the steps of (i) adjusting timing of the input pulse based on a parameter of the second print head, thereby creating a second adjusted pulse; and (ii) printing with the second print head (86) according to the timing of the second adjusted pulse.

49. A method of printing pixels on a printing medium (28), the method comprising:

printing a first pixel row on the printing medium (28) with each of a plurality (n) of uniformly-spaced ink jets (98) of a color such that the first pixel rows are printed with a uniform spacing(s) between adjacent first pixel rows;

advancing the printing medium (28) a first distance (d_1) relative to the print head;

printing a second pixel row with each of the plurality (n) of ink jets (98), each second pixel row being parallel to and

offset from each first pixel row; and

advancing the printing medium (28) a second distance (d_2) relative to the print head;

wherein the first distance is greater than one pixel ($d_1 > 1$),

wherein the second distance is greater than one pixel ($d_2 > 1$), and

wherein the first distance is not equal to the second distance ($d_1 \neq d_2$).

50. The method of claim 49, further characterized by the steps of:

printing a third pixel row with each of the plurality (n) of ink jets (98), each third pixel row being parallel to and offset from each first pixel row and each second pixel row;

advancing the printing medium (28) a third distance (d_3) relative to the print head;

printing a fourth pixel row with each of the plurality (n) of ink jets (98), each fourth pixel row being parallel to and offset from each first pixel row and each second pixel row and each third pixel row; and

advancing the printing medium (28) a fourth distance (d_4) relative to the print head;

wherein the printing medium (28) advances are in a direction perpendicular to the pixel rows,

wherein the sum of the first distance, second distance, third distance and fourth distance is equal to the number of ink

jets (98) of a color times the uniform spacing ($d_1 + d_2 + d_3 + d_4 = n \times s$).

51. The method of claim 50, wherein the first distance is (d_1) 49 pixels, the second distance (d_2) is 45 pixels, the third distance (d_3) is 49 pixels, the fourth distance (d_4) is 49 pixels, the number of ink jets (98) of a color (n) is 48, and the uniform spacing between adjacent first pixel rows (s) is 4 pixels.

52. The method of claim 49, wherein the first distance in pixels is within three of the number of ink jets (98) of a color ($n - 3 \leq d_1 \leq n + 3$).

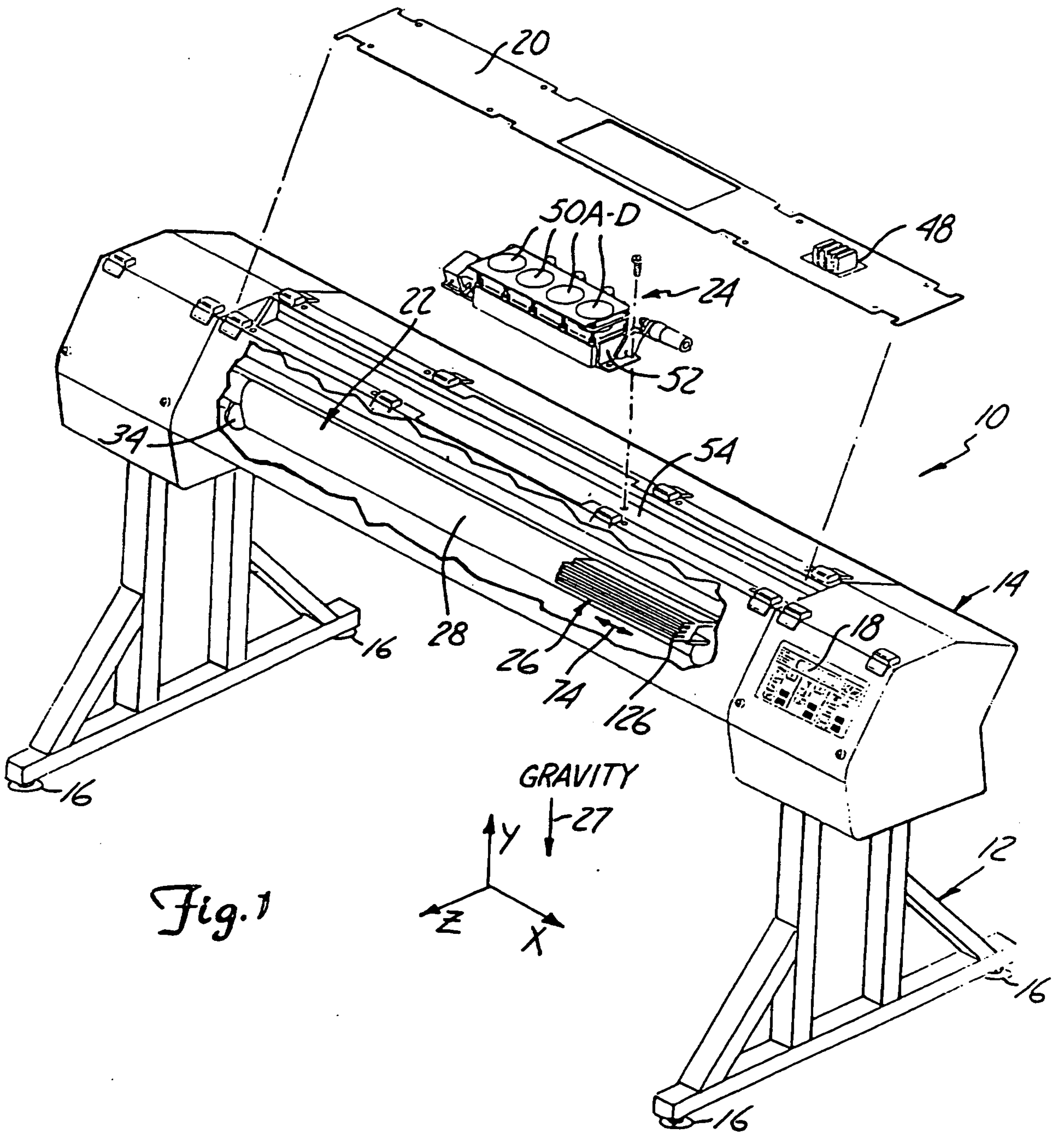
20
50A-D
48
24
22
52
10
34
54
14
18
28
16
26
74
126
16
GRAVITY
27
Y
Z
X
12
16
16

Fig. 1

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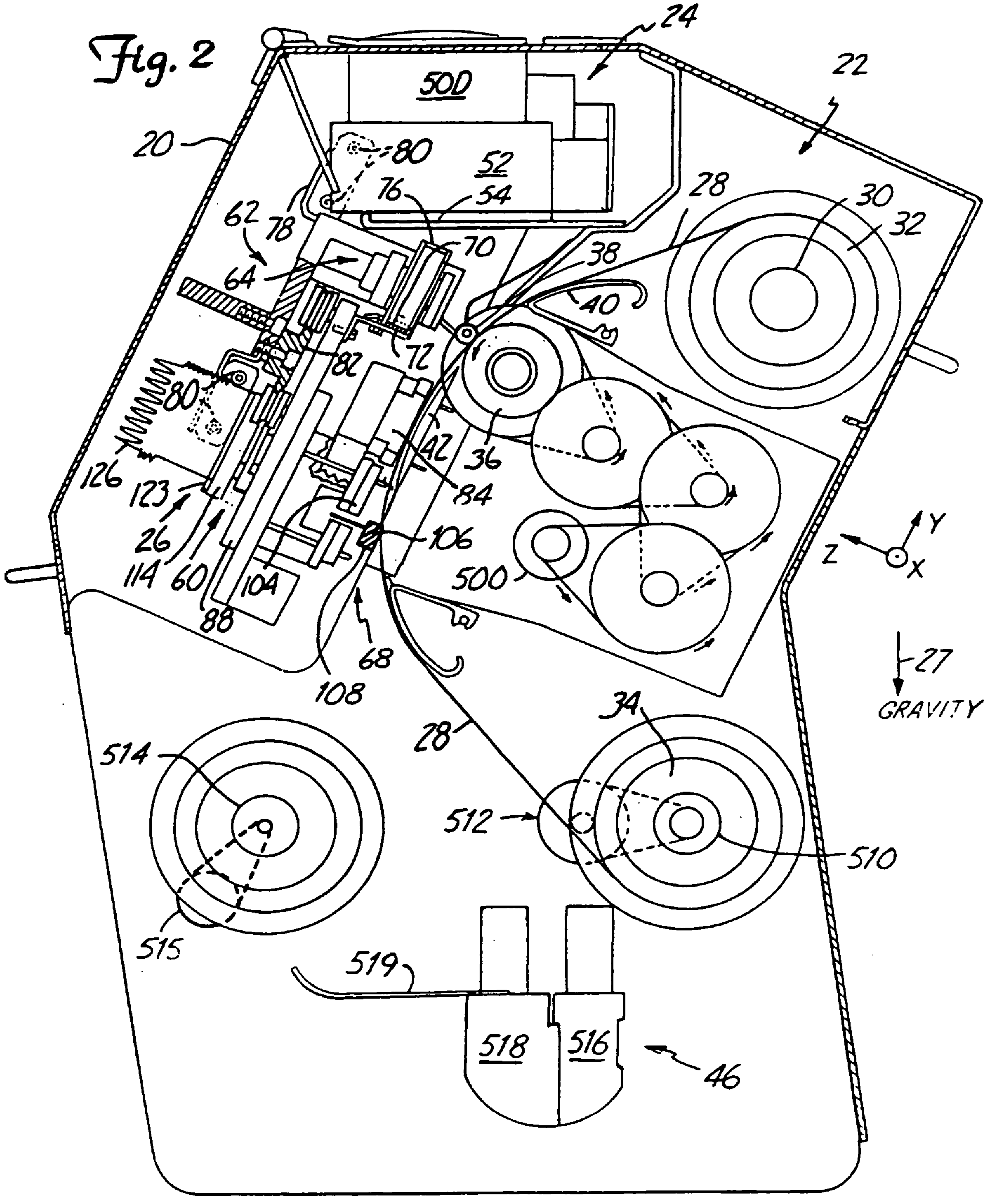
Fig. 2


24
22
50D
20
80
52
76
54
28
62
78
70
30
32
64
38
40
72
82
80
126
42
36
84
123
26
106
500
Y
Z
X
114
60
10A
88
68
27
GRAVITY
108
28
34
514
512
510
515
519
518
516
46

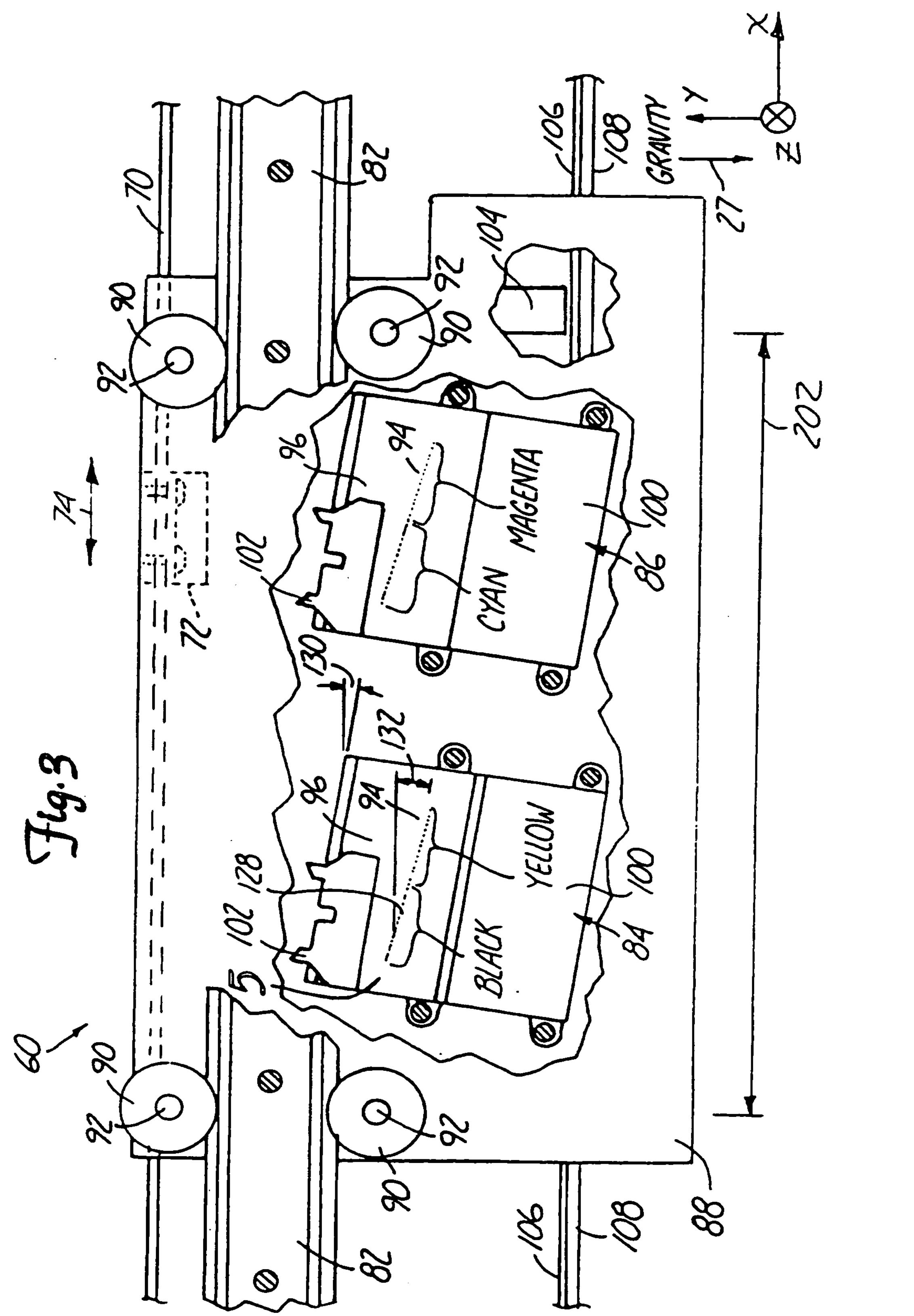
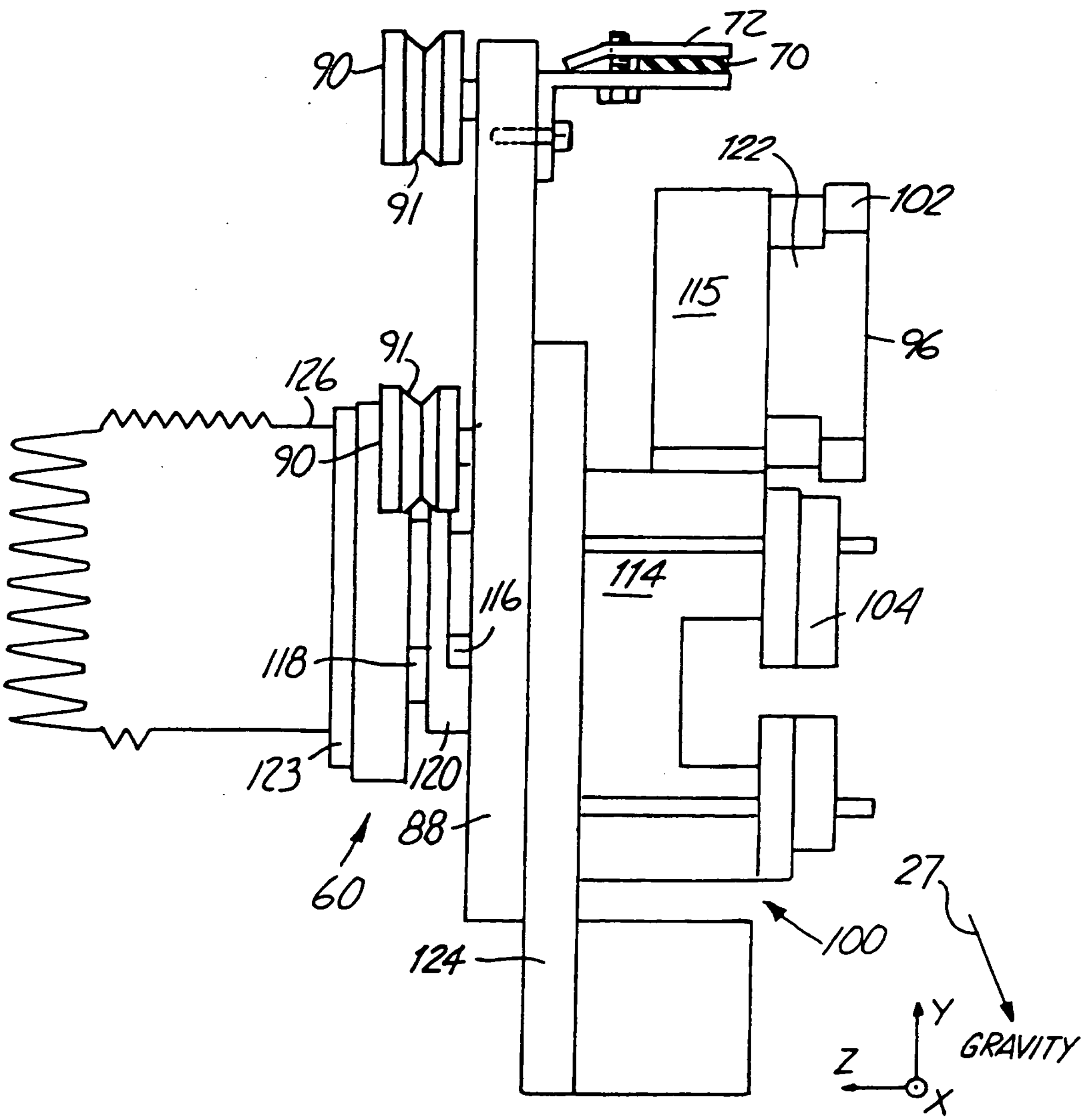


Fig.3

Fig. 4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100
Y
Z
X
GRAVITY

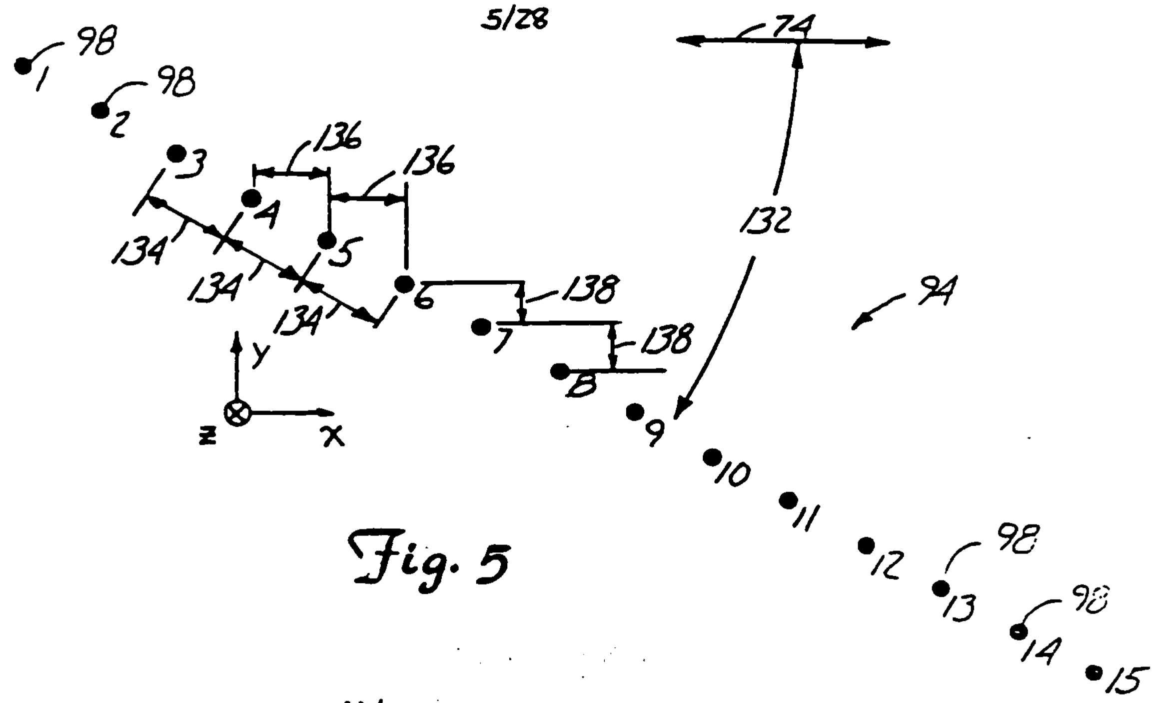


Fig. 5

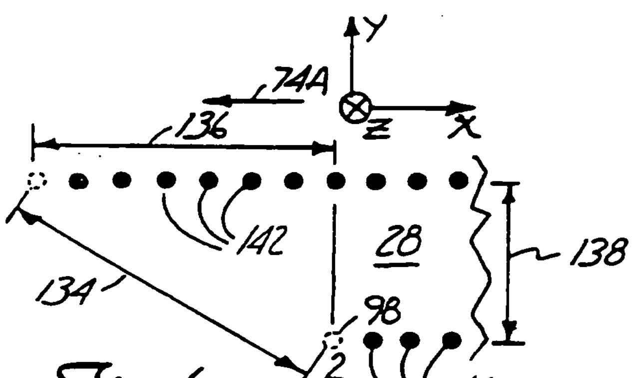


Fig. 6

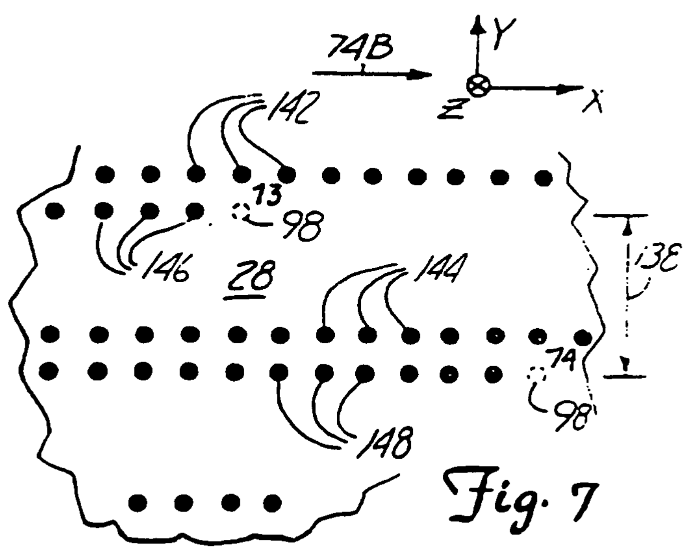


Fig. 7

150 152 154

Pixel Row	Pass #	Jet #
1	.	.
2	.	.
3	.	.
4	.	.
5	.	.
6	.	.
7	.	.
8	.	.
9	.	.
10	.	.
11	.	.
12	.	.
13	.	.
14	.	.
15	.	.
16	.	.
17	.	.
18	.	.
19	.	.
20	.	.
21	.	.
22	.	.
23	.	.
24	.	.
25	.	.
26	.	.
27	.	.
28	.	.
29	.	.
30	.	.
31	.	.
32	1	1
33	.	.
34	.	.
35	.	.
36	1	2

Fig. 8A

150 152 154

Pixel Row	Pass #	Jet #
1	.	.
2	.	.
3	.	.
4	.	.
5	.	.
6	.	.
7	.	.
8	.	.
9	.	.
10	.	.
11	.	.
12	.	.
13	.	.
14	.	.
15	.	.
16	.	.
17	.	.
18	.	.
19	.	.
20	.	.
21	.	.
22	.	.
23	.	.
24	.	.
25	.	.
26	.	.
27	2	1
28	.	.
29	.	.
30	.	.
31	2	2
32	1	1
33	.	.
34	.	.
35	2	3
36	1	2

Fig. 8B

150 152 154

Pixel Row	Pass #	Jet #
1	.	.
2	.	.
3	.	.
4	.	.
5	.	.
6	.	.
7	.	.
8	.	.
9	.	.
10	.	.
11	.	.
12	.	.
13	.	.
14	.	.
15	.	.
16	.	.
17	.	.
18	.	.
19	.	.
20	.	.
21	.	.
22	.	.
23	.	.
24	.	.
25	3	1
26	.	.
27	2	1
28	.	.
29	3	2
30	.	.
31	2	2
32	1	1
33	3	3
34	.	.
35	2	3
36	1	2

Fig. 8C

150 152 154

Pixel Row	Pass #	Jet #
1	.	.
2	.	.
3	.	.
4	.	.
5	.	.
6	.	.
7	.	.
8	.	.
9	.	.
10	.	.
11	.	.
12	.	.
13	.	.
14	.	.
15	.	.
16	.	.
17	.	.
18	.	.
19	.	.
20	.	.
21	.	.
22	4	1
23	.	.
24	.	.
25	3	1
26	4	2
27	2	1
28	.	.
29	3	2
30	4	3
31	2	2
32	1	1
33	3	3
34	4	4
35	2	3
36	1	2

Fig. 8D

150 152 154

Pixel Row	Pass #	Jet #
1	.	.
2	.	.
3	.	.
4	.	.
5	.	.
6	.	.
7	.	.
8	.	.
9	.	.
10	.	.
11	.	.
12	.	.
13	.	.
14	.	.
15	.	.
16	5	1
17	.	.
18	.	.
19	.	.
20	5	2
21	.	.
22	4	1
23	.	.
24	5	3
25	3	1
26	4	2
27	2	1
28	5	4
29	3	2
30	4	3
31	2	2
32	1	1
33	3	3
34	4	4
35	2	3
36	1	2

Fig. 8E

150 152 154

Pixel Row	Pass #	Jet #
1	11	3
2	12	4
3	10	3
4	9	2
5	11	4
6	8	1
7	10	4
8	9	3
9	7	1
10	8	2
11	6	1
12	9	4
13	7	2
14	8	3
15	6	2
16	5	1
17	7	3
18	8	4
19	6	3
20	5	2
21	7	4
22	4	1
23	6	4
24	5	3
25	3	1
26	4	2
27	2	1
28	5	4
29	3	2
30	4	3
31	2	2
32	1	1
33	3	3
34	4	4
35	2	3
36	1	2

$s=4$

$n=4$

$d_4=6$

$d_3=3$

$d_2=2$

$d_1=5$

Fig. 8F

150 152 154

Pixel Row	Pass #	Jet #
1	12	4
2	11	3
3	10	2
4	9	1
5	8	1
6	11	4
7	10	3
8	9	2
9	8	2
10	7	1
11	10	4
12	9	3
13	8	3
14	7	2
15	6	1
16	9	4
17	8	4
18	7	3
19	6	2
20	5	1
21	4	1
22	7	4
23	6	3
24	5	2
25	4	2
26	3	1
27	6	4
28	5	3
29	4	3
30	3	2
31	2	1
32	5	4
33	4	4
34	3	3
35	2	2
36	1	1

$s=4$

$n=4$

$d_4=1$

$d_3=5$

$d_2=5$

$d_1=5$

Fig. 8G

150 152 154

Pixel Row	Pass #	Jet #
1	10	2
2	11	3
3	12	4
4	9	2
5	10	3
6	11	4
7	8	1
8	9	3
9	10	4
10	7	1
11	8	2
12	9	4
13	6	1
14	7	2
15	8	3
16	5	1
17	6	2
18	7	3
19	8	4
20	5	2
21	6	3
22	7	4
23	4	1
24	5	3
25	6	4
26	3	1
27	4	2
28	5	4
29	2	1
30	3	2
31	4	3
32	1	1
33	2	2
34	3	3
35	4	4
36	1	2

$s=4$

$n=4$

$d_4=7$

$d_3=3$

$d_2=3$

$d_1=3$

Fig. 8H

150 152 154

Pixel Row	Pass #	Jet #
1	9	2
2	7	1
3	8	2
4	9	3
5	7	2
6	8	3
7	6	1
8	7	3
9	5	1
10	6	2
11	4	1
12	5	2
13	6	3
14	4	2
15	5	3
16	3	1
17	4	3
18	2	1
19	3	2
20	1	1

$S=3$
$n=3$
$d_3=5$
$d_2=2$
$d_1=2$

Fig. 9

150 152 154

Pixel Row	Pass #	Jet #
1	6	2
2	8	4
3	5	1
4	6	3
5	7	4
6	5	2
7	6	4
8	4	1
9	5	3
10	3	1
11	4	2
12	5	4
13	3	2
14	4	3
15	2	1
16	3	3
17	4	4
18	2	2
19	3	4
20	1	1

$S=3$
$n=4$
$d_3=2$
$d_2=5$
$d_1=5$

Fig. 10

150 152 154

Pixel Row	Pass #	Jet #
1	5	1
2	8	37
3	7	26
4	6	14
5	5	2
6	8	38
7	7	27
8	6	15
9	5	3
45	5	12
46	8	48
47	7	37
48	6	25
49	5	13
50	4	1
51	7	38
52	6	26
53	5	14
54	4	2
92	6	36
93	5	24
94	4	12
95	3	1
96	6	37
97	5	25
98	4	13
99	3	2
100	6	38

$d_4 = 49$

$d_3 = 45$

$d_2 = 49$

150 152 154

Pixel Row	Pass #	Jet #
101	5	26
102	4	14
140	6	48
141	5	36
142	4	24
143	3	13
144	2	1
145	5	37
146	4	25
147	3	14
149	2	2
188	2	12
189	5	48
190	4	36
191	3	25
192	2	13
193	1	1
194	4	37
195	3	26
196	2	14
197	1	2
235	3	36
236	2	24
237	1	12
238	4	48
239	3	37
240	2	25

$d_2 = 49$

$d_1 = 49$

$S = 4$

$n = 48$

Fig. 11

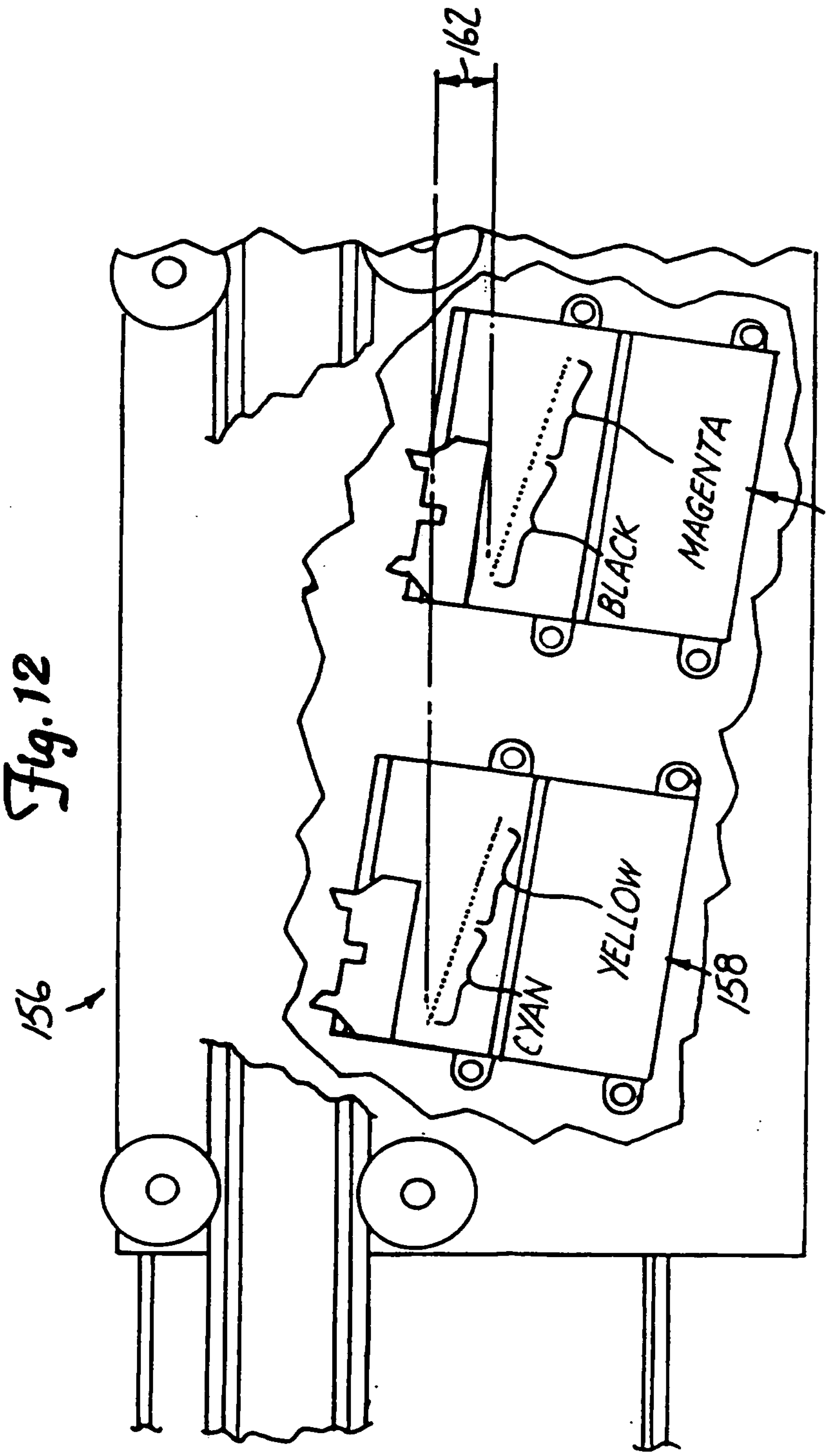
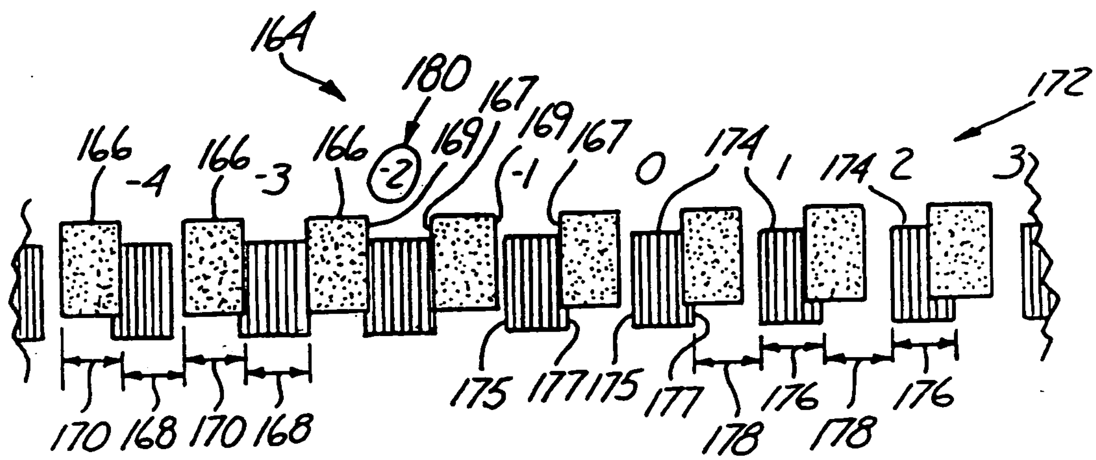


Fig. 12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180
167
169
169
167
172
166
-4
166
-3
166
-2
-1
0
174
1
174
2
3
175
177
175
177
176
176
170
168
170
168
178
178

Fig. 13

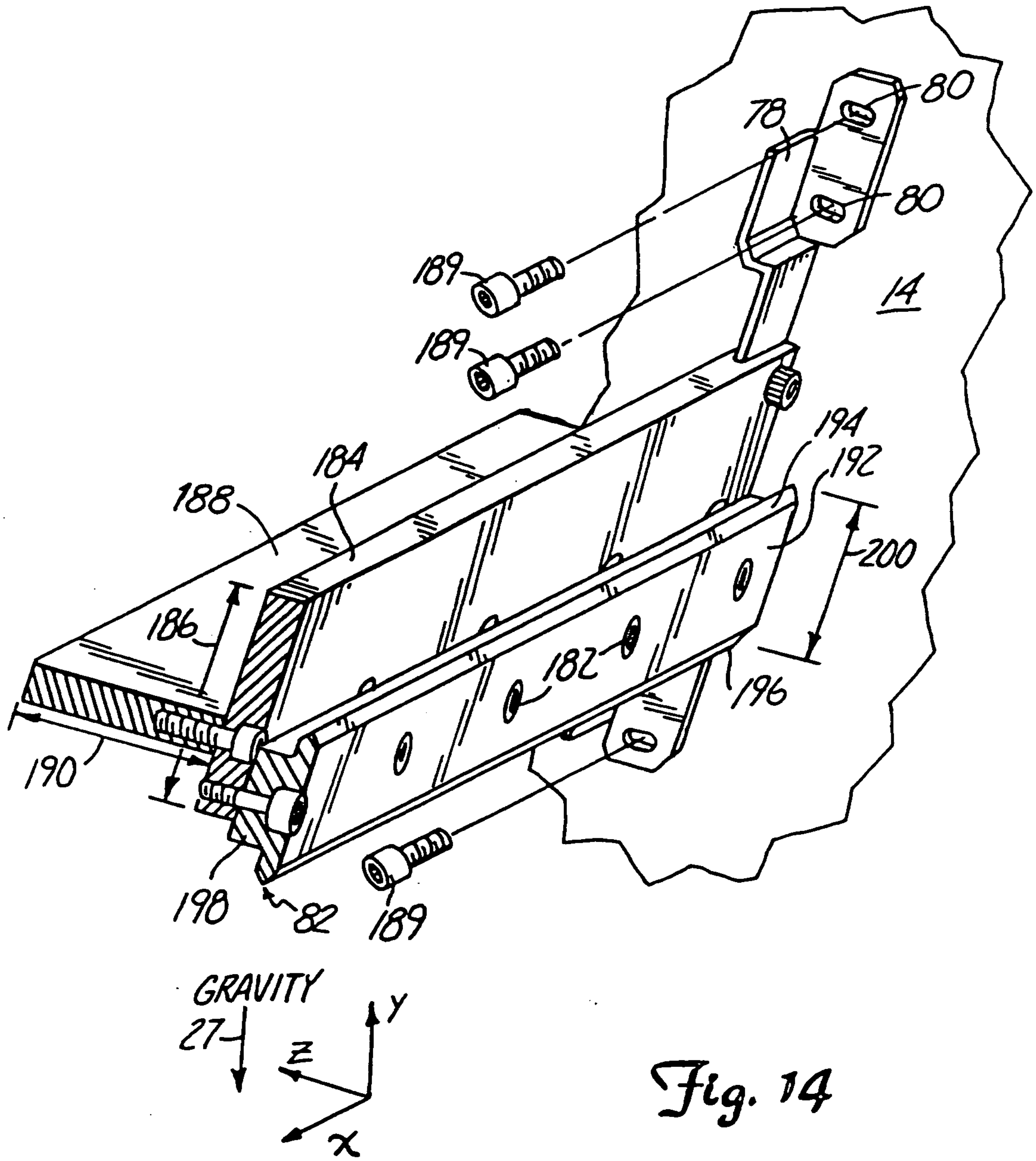
80
78
80
189
189
14
194
192
184
188
200
186
182
196
190
198
82
189
GRAVITY
27
Y
Z
X

Fig. 14

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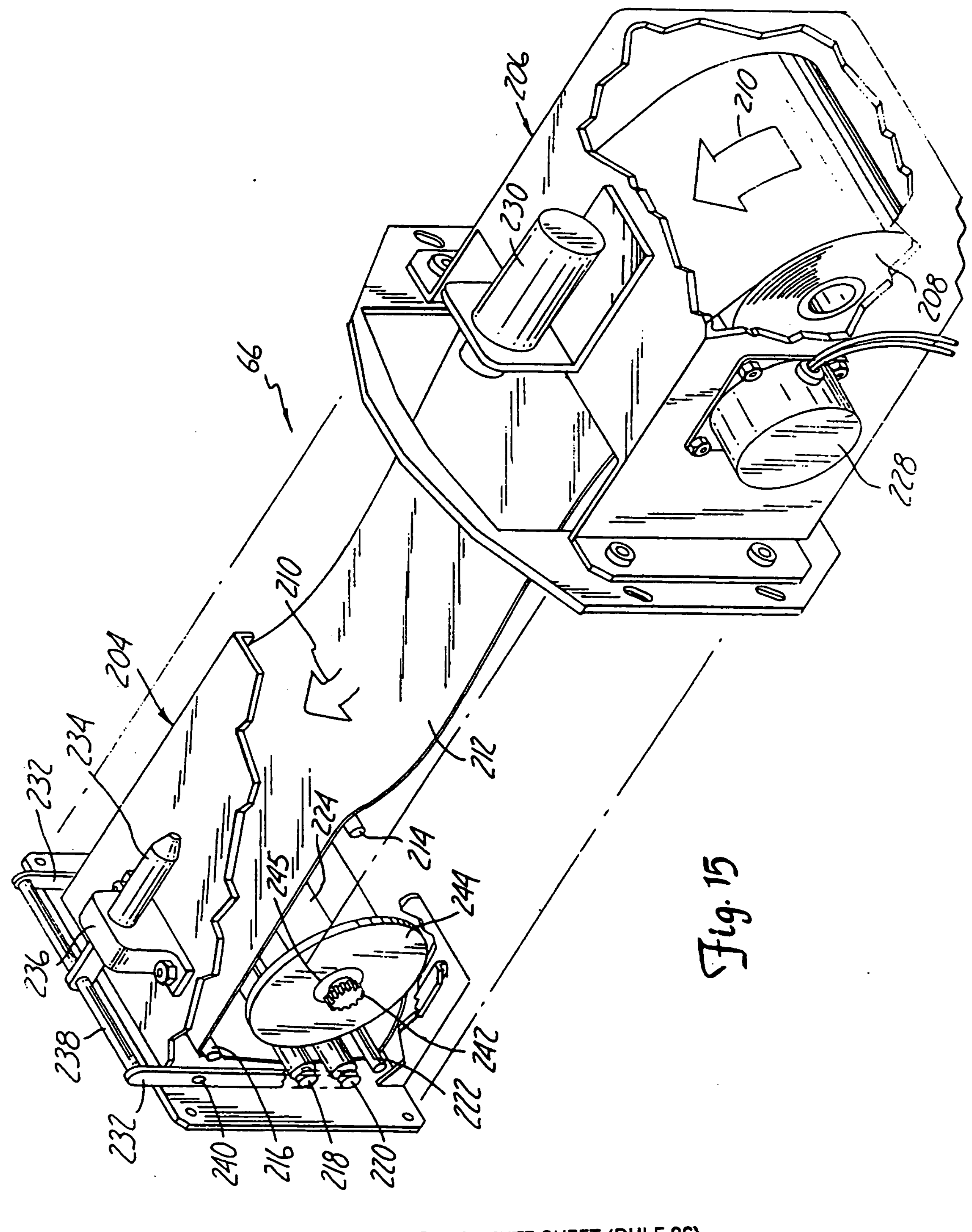
206
210
230
208
228
66
210
204
212
232
234
214
224
245
244
236
238
232
240
216
218
220
222
242

Fig. 15

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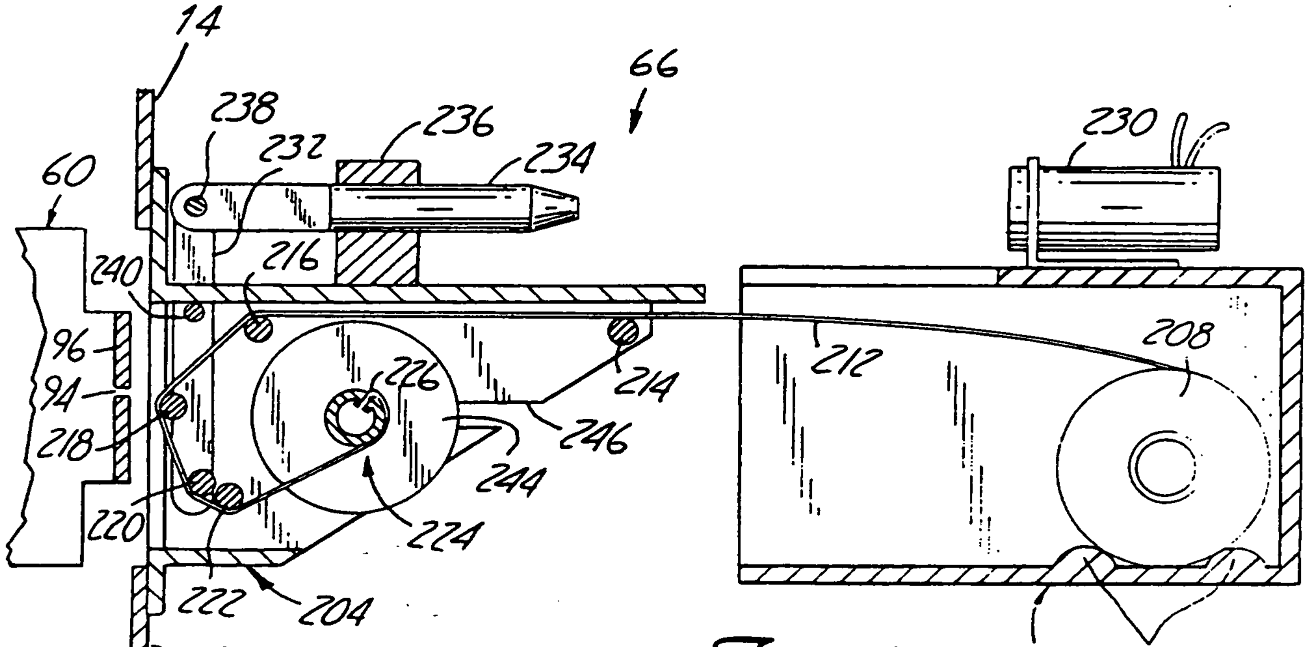

14
66
238
236
232
234
230
60
240
216
96
94
218
212
208
226
214
246
244
224
220
222
204
14
206
248

Fig. 16

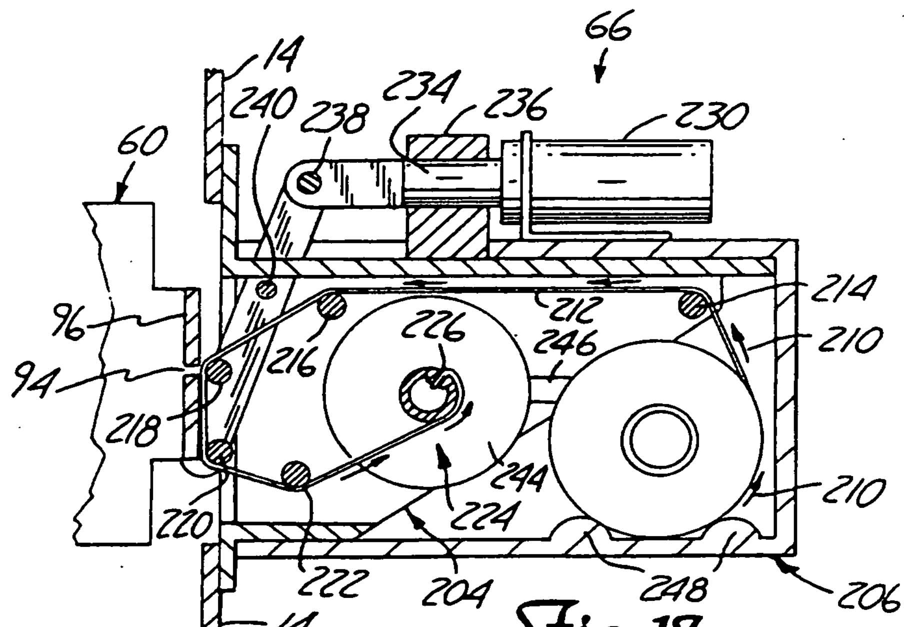

66
14
240
238
234
236
230
60
96
94
218
220
216
226
212
246
214
210
244
224
210
222
204
248
206
14

Fig. 17

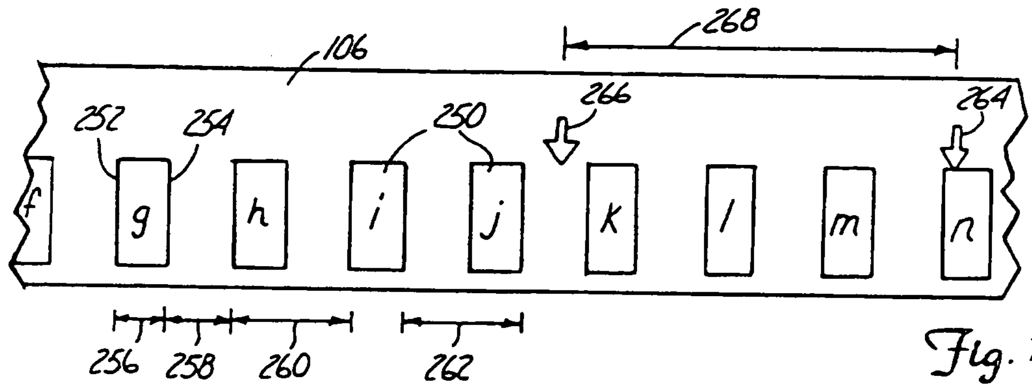


Fig. 18

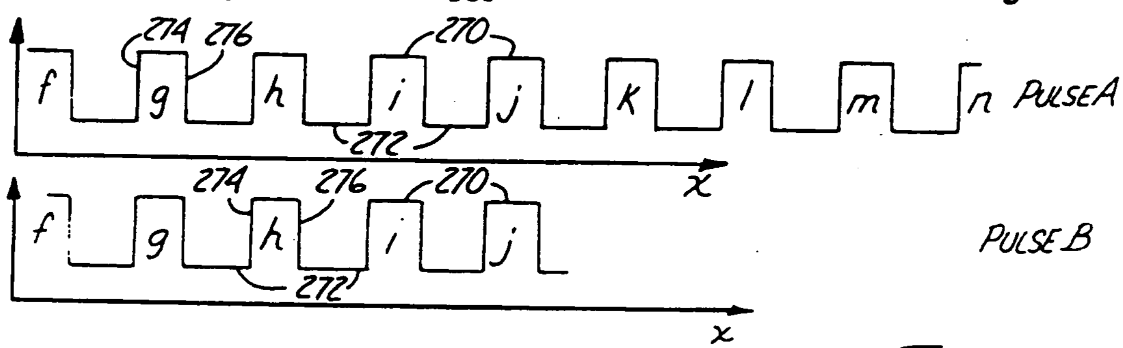


Fig. 19

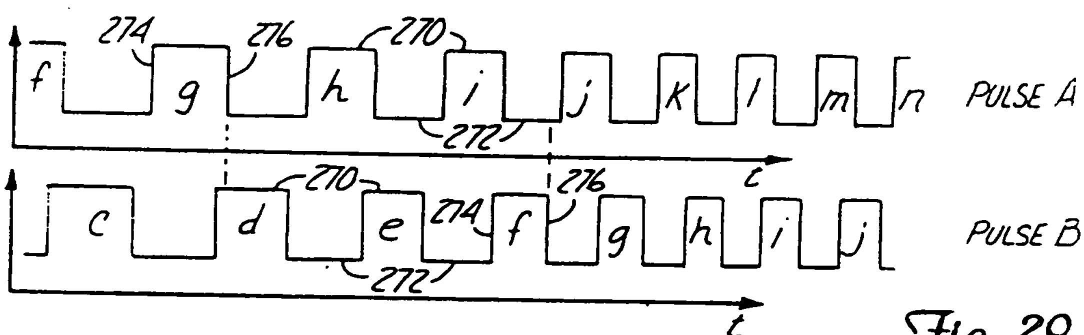


Fig. 20

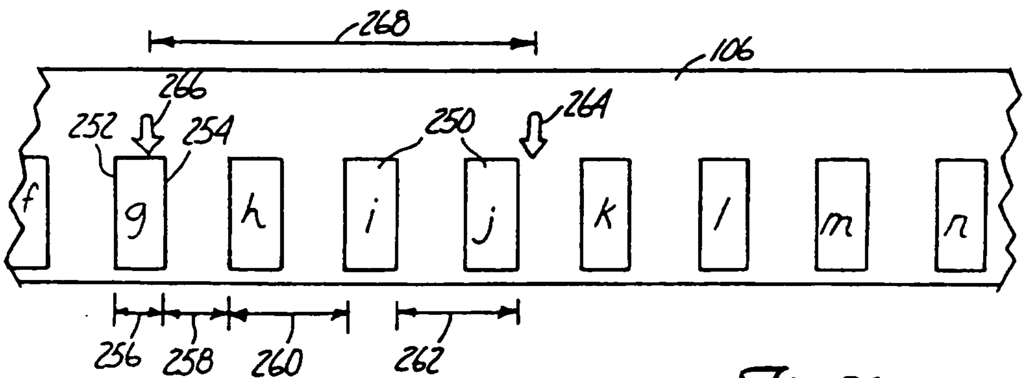


Fig. 21

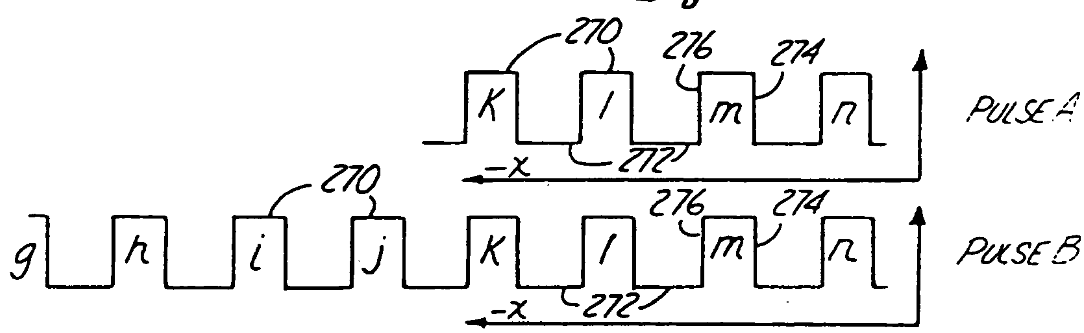


Fig. 22

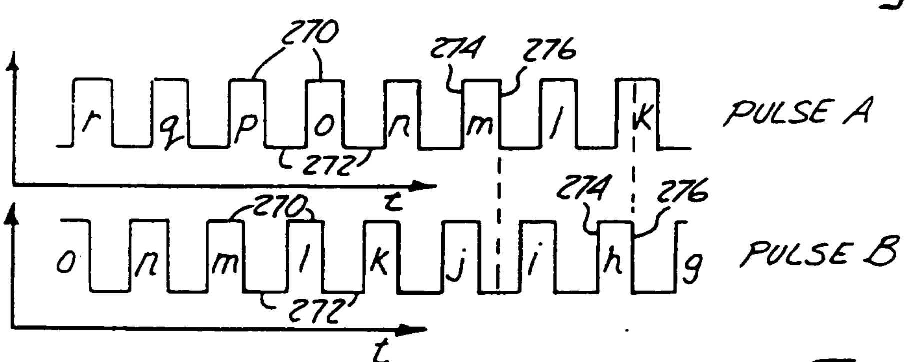
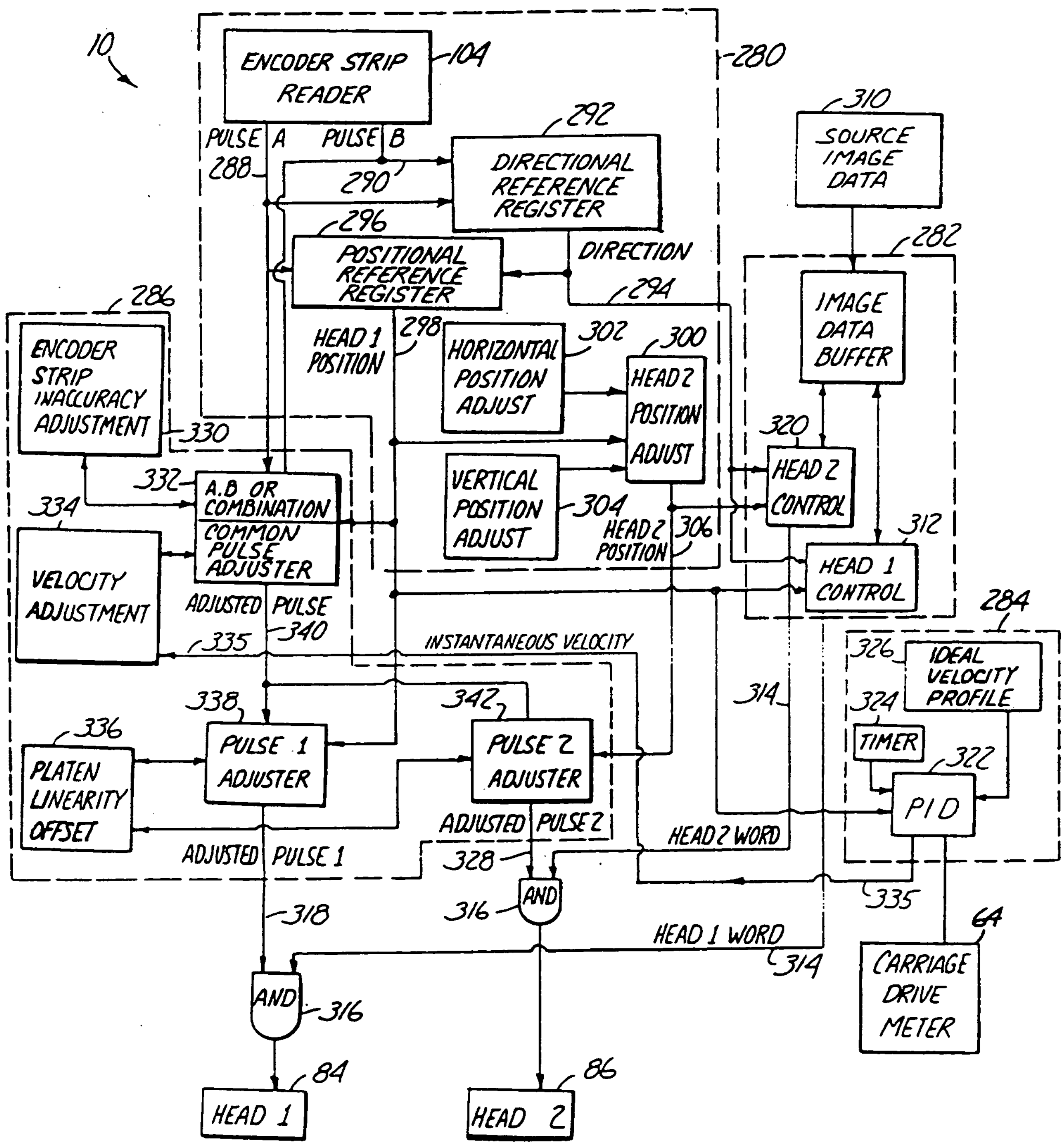


Fig. 23

Fig. 24


10
ENCODER STRIP READER
104
280
PULSE A
PULSE B
288
290
DIRECTIONAL REFERENCE REGISTER
292
296
POSITIONAL REFERENCE REGISTER
DIRECTION
294
310
SOURCE IMAGE DATA
282
IMAGE DATA BUFFER
286
ENCODER STRIP INACCURACY ADJUSTMENT
330
HEAD 1 POSITION
298
HORIZONTAL POSITION ADJUST
302
300
HEAD 2 POSITION ADJUST
320
HEAD 2 CONTROL
332
A.B OR COMBINATION
COMMON PULSE ADJUSTER
334
VELOCITY ADJUSTMENT
VERTICAL POSITION ADJUST
304
HEAD 2 POSITION
306
312
HEAD 1 CONTROL
284
ADJUSTED PULSE
340
335
INSTANTANEOUS VELOCITY
326
IDEAL VELOCITY PROFILE
314
324
TIMER
322
PID
338
342
336
PLATEN LINEARITY OFFSET
PULSE 1 ADJUSTER
PULSE 2 ADJUSTER
ADJUSTED PULSE 2
HEAD 2 WORD
ADJUSTED PULSE 1
328
335
AND
316
318
HEAD 1 WORD
314
64
CARRIAGE DRIVE METER
AND
316
84
86
HEAD 1
HEAD 2

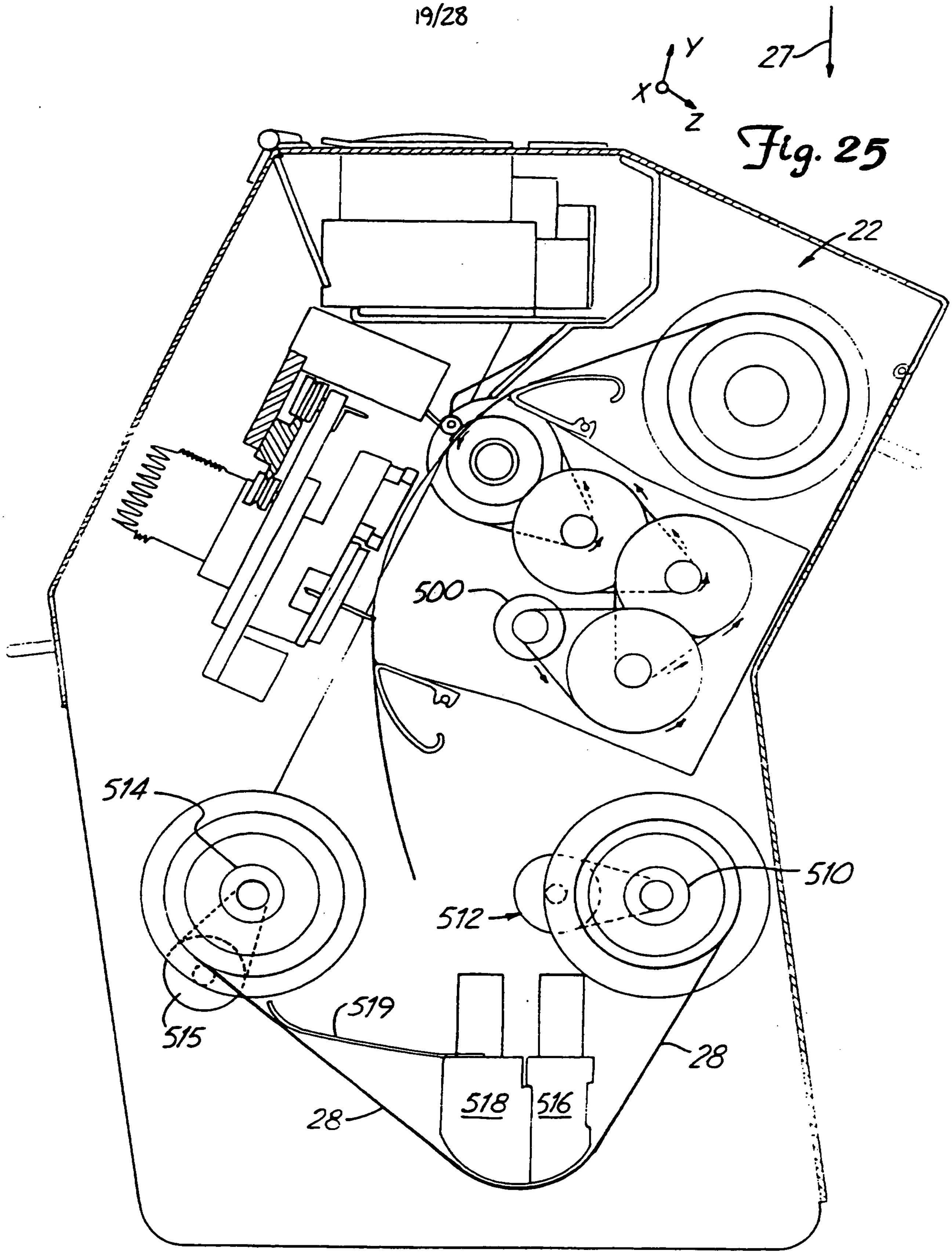


Fig. 25

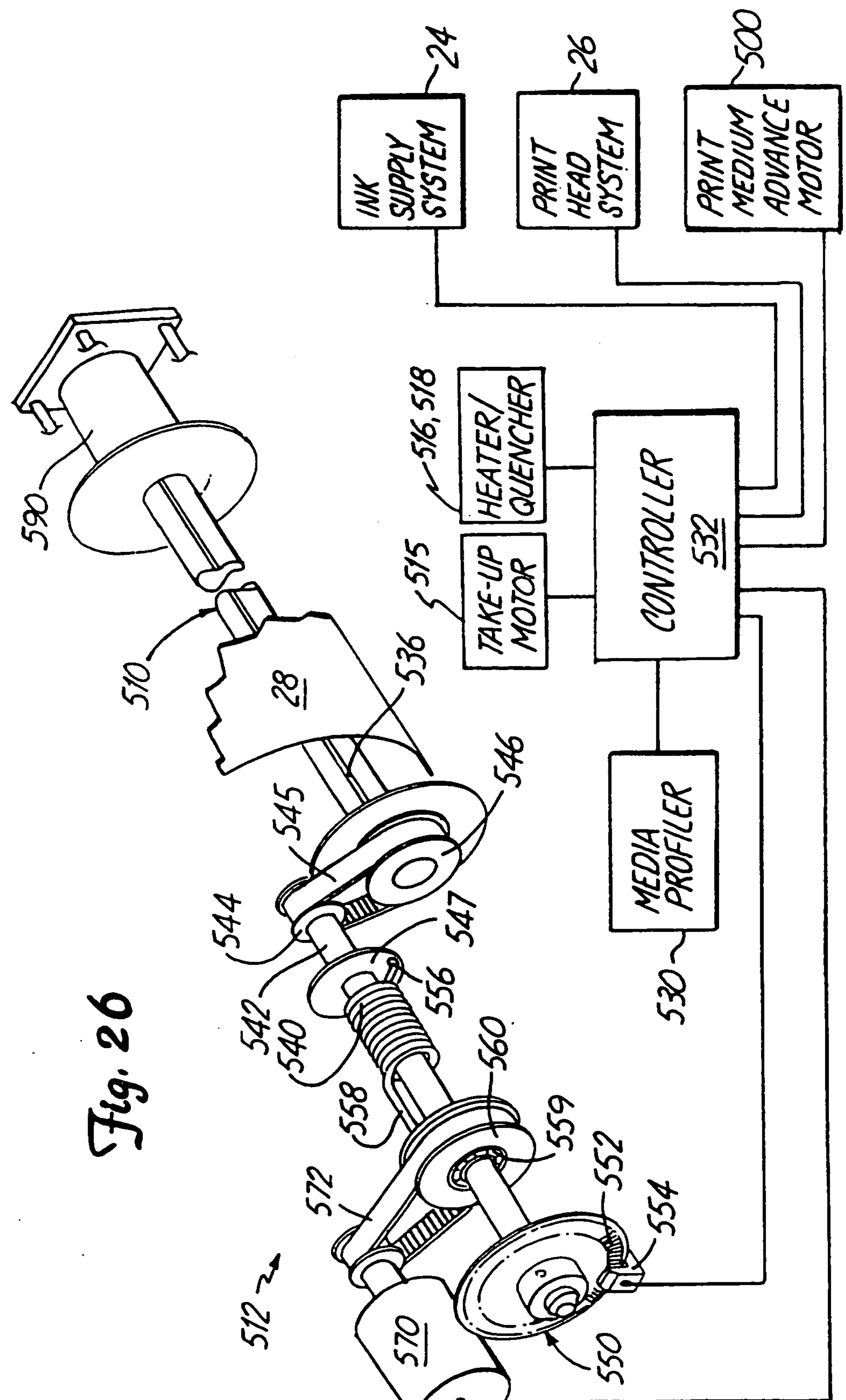

INK SUPPLY SYSTEM
24
PRINT HEAD SYSTEM
26
PRINT MEDIUM ADVANCE MOTOR
500
HEATER/ QUENCHER
516, 518
TAKE-UP MOTOR
515
CONTROLLER
532
MEDIA PROFILER
530
590
510
28
536
546
545
544
547
556
542
540
560
558
559
552
554
572
512
570
550

Fig. 26

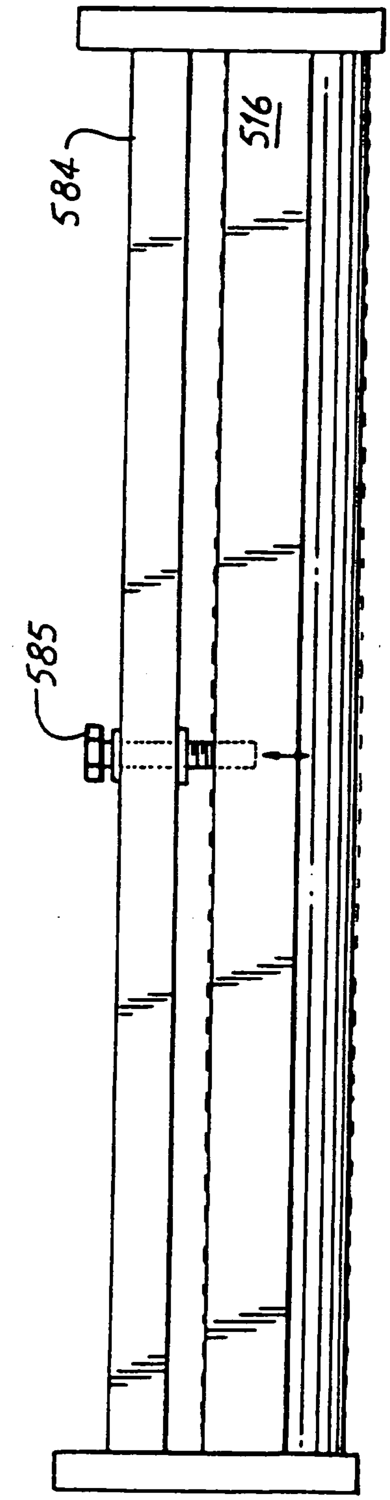


Fig. 27

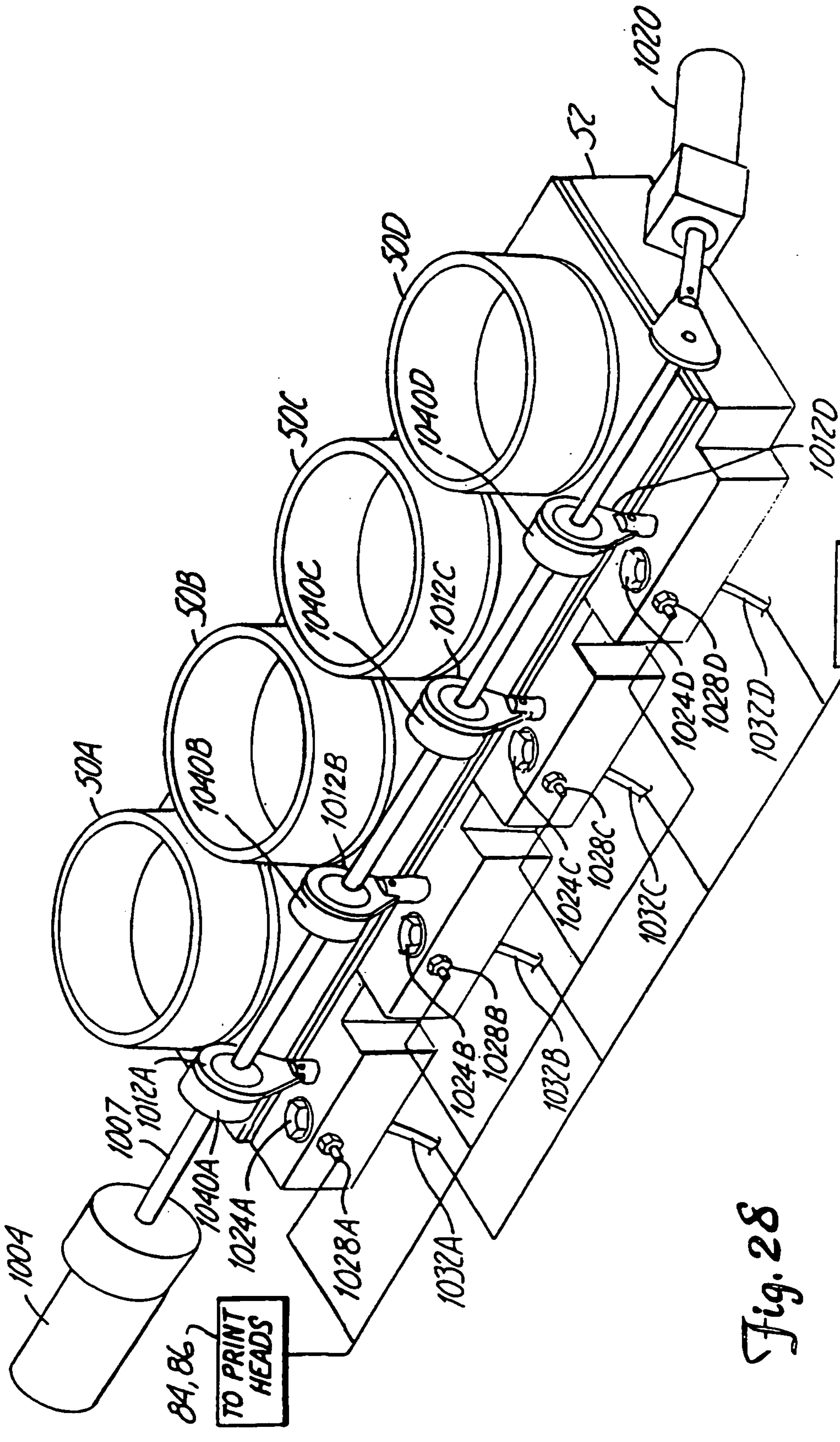

1004
1007
1012A
1040A
1024A
1028A
1032A
84,86
TO PRINT HEADS
50A
1040B
1012B
1024B
1028B
1032B
50B
1040C
1012C
1024C
1028C
1032C
50C
1040D
1012D
1024D
1028D
1032D
50D
52
1020
TO DRAIN
1036

Fig. 28

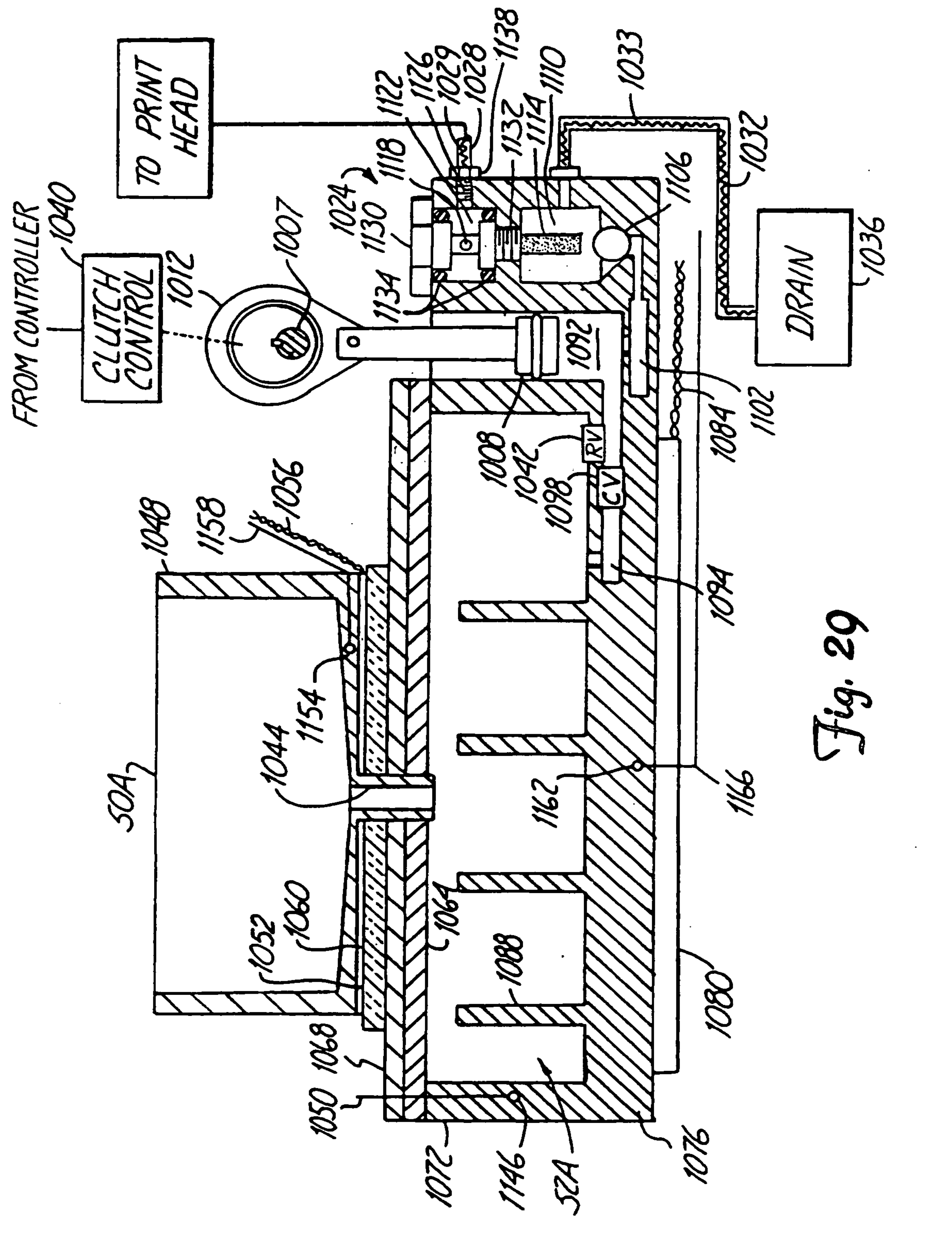

FROM CONTROLLER
CLUTCH CONTROL
1040
TO PRINT HEAD
DRAIN
1036
RV
CV
1012
1007
1024
1130
1118
1122
1126
1029
1028
1138
1132
1114
1110
1033
1032
1106
1134
1092
1008
1042
1098
1084
1102
1094
1048
1158
1056
1154
1044
50A
1162
1166
1052
1060
1064
1088
1080
1068
1050
1072
1146
52A
1076

Fig. 29

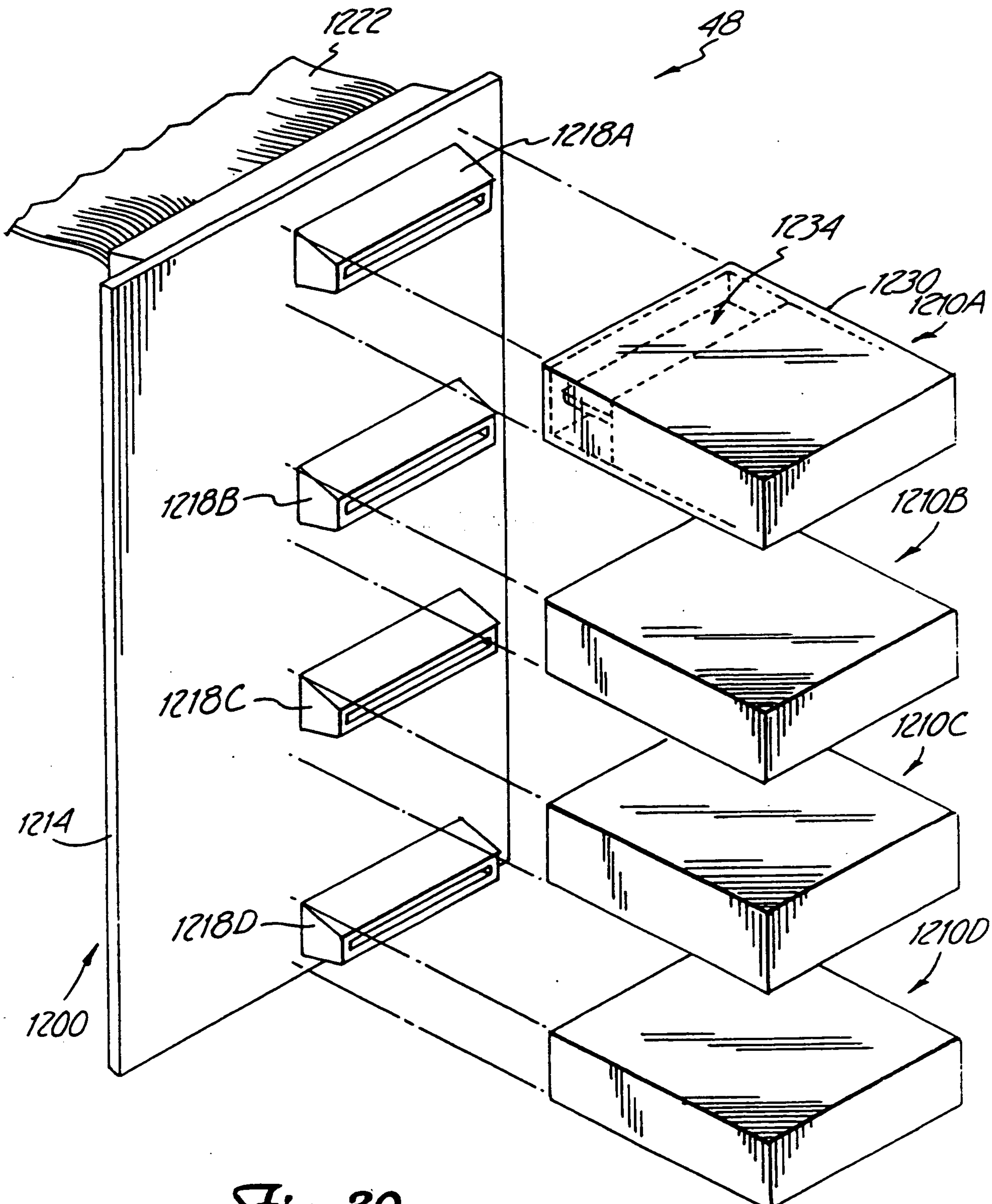

1222
48
1218A
1234
1230
1210A
1218B
1210B
1218C
1210C
1214
1218D
1210D
1200

Fig. 30

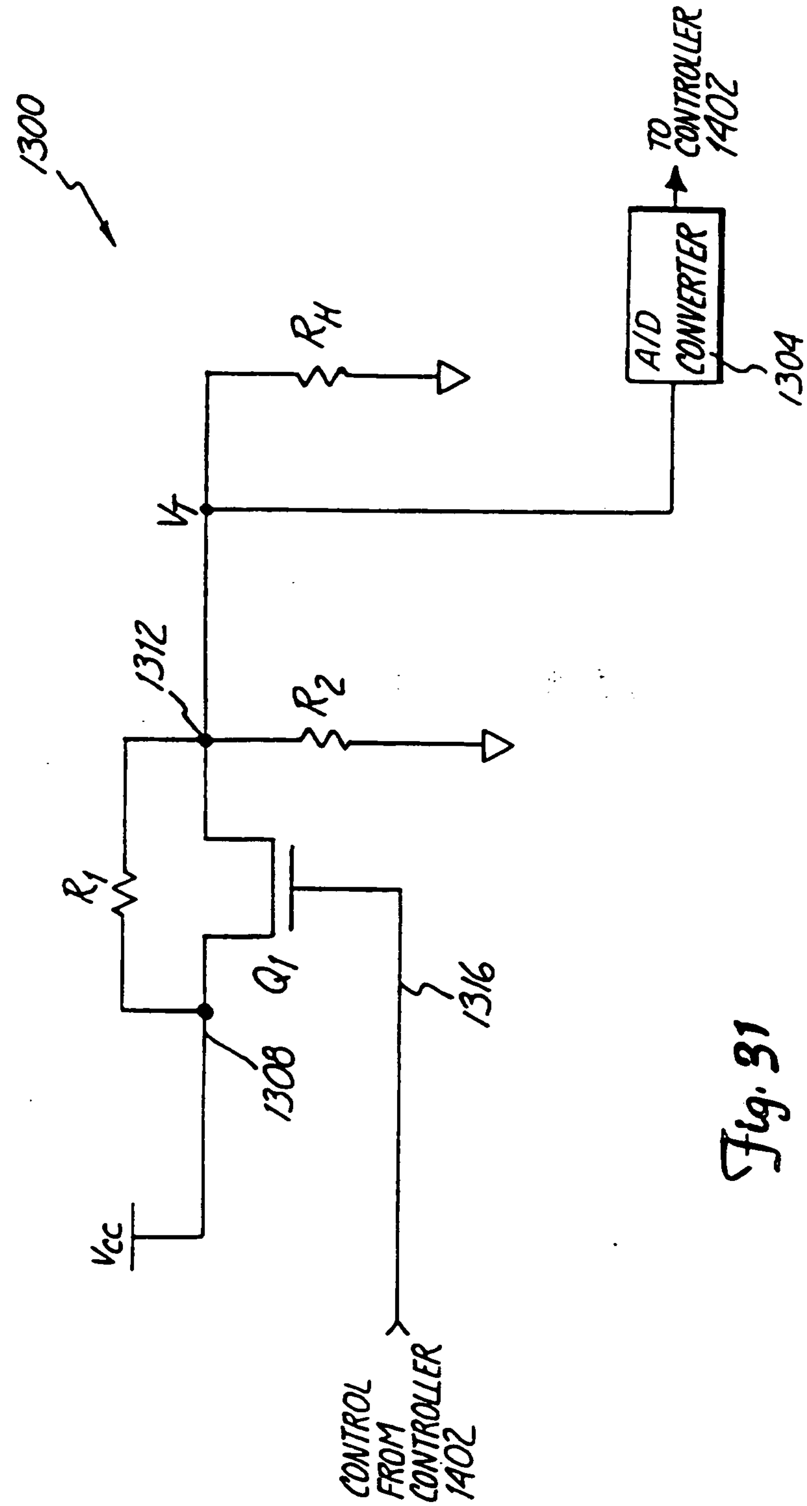
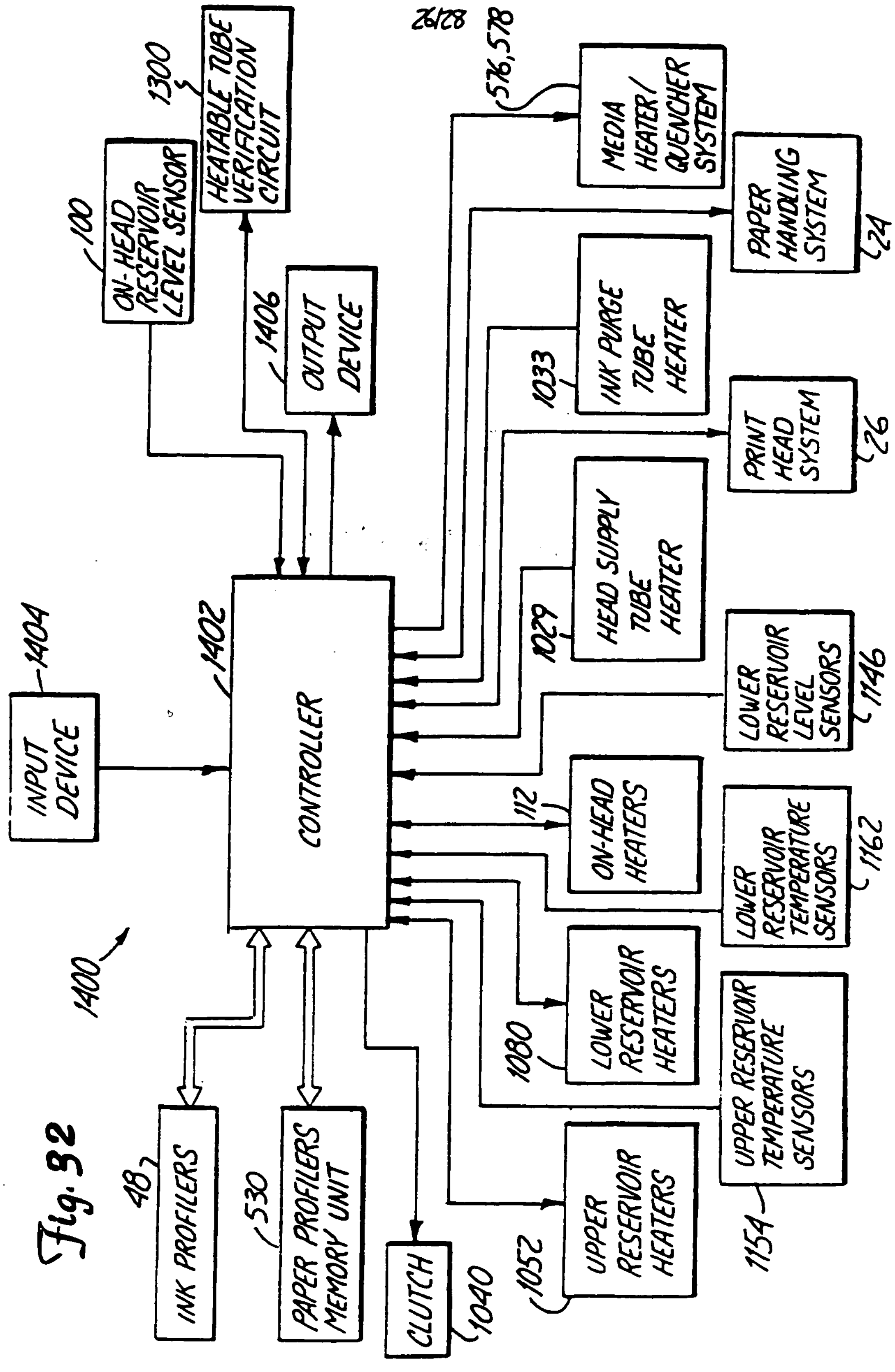

1300
TO CONTROLLER 1402
A/D CONVERTER
1304
R_H
V_T
1312
R_2
R_1
Q_1
1316
1308
V_{CC}
CONTROL FROM CONTROLLER 1402

Fig. 31



1400
INPUT DEVICE
1404
CONTROLLER
1402
ON-HEAD RESERVOIR LEVEL SENSOR
100
HEATABLE TUBE VERIFICATION CIRCUIT
1300
OUTPUT DEVICE
1406
MEDIA HEATER/ QUENCHER SYSTEM
576,578
PAPER HANDLING SYSTEM
24
INK PURGE TUBE HEATER
1033
PRINT HEAD SYSTEM
26
HEAD SUPPLY TUBE HEATER
1029
LOWER RESERVOIR LEVEL SENSORS
1146
ON-HEAD HEATERS
112
LOWER RESERVOIR TEMPERATURE SENSORS
1162
LOWER RESERVOIR HEATERS
1080
UPPER RESERVOIR TEMPERATURE SENSORS
1154
UPPER RESERVOIR HEATERS
1052
INK PROFILERS
48
PAPER PROFILERS MEMORY UNIT
530
CLUTCH
1040

Fig. 32

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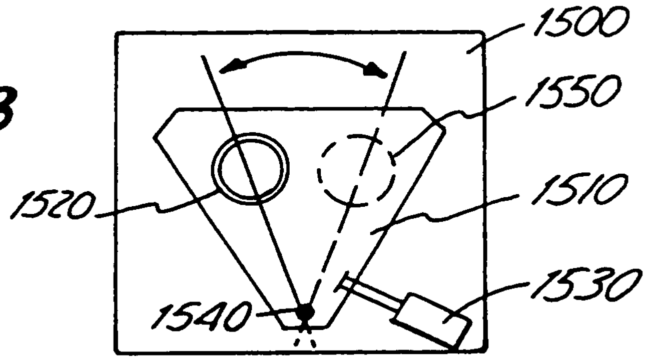
1500
1550
1510
1520
1530
1540

Fig. 33

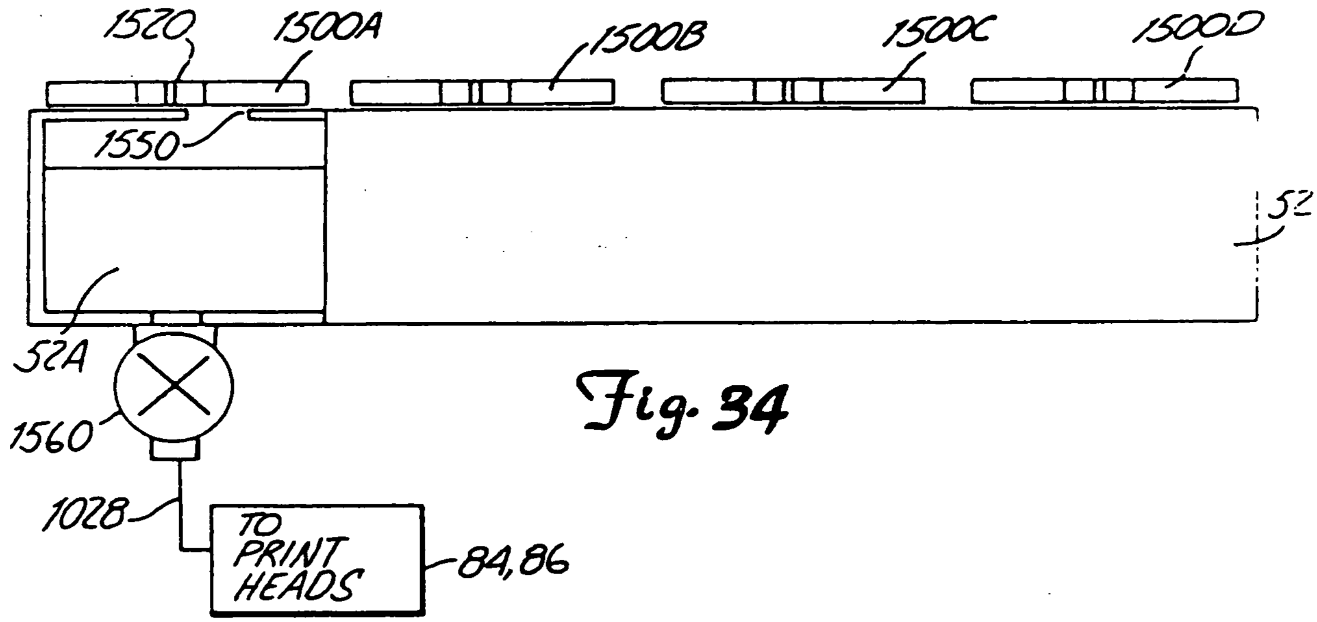
1520
1500A
1500B
1500C
1500D
1550
52
52A
1560
1028
TO PRINT HEADS
84,86

Fig. 34

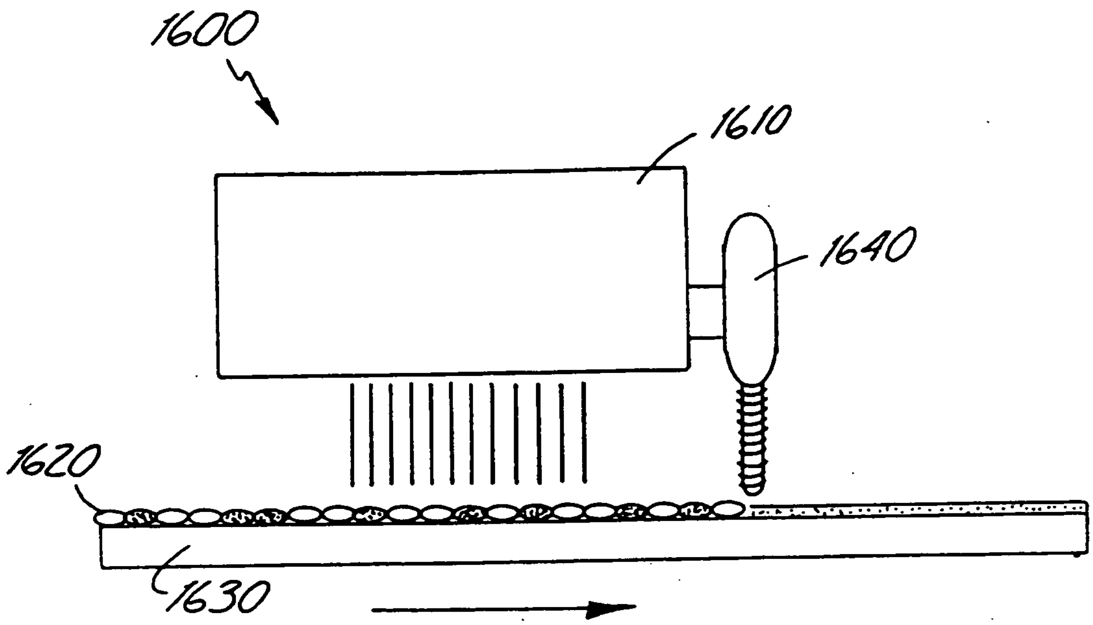

Fig. 35